EDWARD HENRY SCOTT

Vols. 1/2

A SYSTEM

OF

FAMILIAR PHILOSOPHY:

IN

TWELVE LECTURES;

BEING THE COURSE USUALLY READ BY

MR. A. WALKER.

CONTAINING

THE ELEMENTS AND THE PRACTICAL USES TO BE DRAWN FROM THE
CHEMICAL PROPERTIES OF MATTER: THE PRINCIPLES AND
APPLICATION OF MECHANICS; OF HYDROSTATICS;
OF HYDRAULICS; OF PNEUMATICS; OF
MAGNETISM; OF ELECTRICITY;
OF OPTICS; AND OF
ASTRONOMY.

INCLUDING EVERY MATERIAL MODERN DISCOVERY AND
IMPROVEMENT TO THE PRESENT TIME.

*ILLUSTRATED BY FORTY-NINE COPPER-PLATES, NEATLY AND ACCURATELY
ENGRAVED.*

A NEW EDITION; IN TWO VOLUMES.

VOL. I.

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PREFACE.

INSTINCT is the voice of God; it directs our firſt motions to feel, ſee, hear, taſte, and ſmell, every thing that comes in our way. Here begins the firſt chapter of experimental philoſophy; here is laid the corner ſtone for our knowledge of Nature and her laws: for at a time when a nurſe ſuppoſes a child is only amuſing itſelf by ſtriving to catch hold of every thing within and without its reach, it is laying in a ſtock of important information! By this propenſity, we learn to know diſtances, hardneſs, ſoftneſs, painful and pleaſurable objects, heat, cold, and many other qualities of bodies, long before it is ſuſpected by the unobſerving part of mankind. Curioſity being thus natural to the ſoul of man, we are ſolicitous after every ſpecies of information; and it would be extremely unnatural to ſuppoſe we ſhould be leſs inquiſitive, leſs ſolicitous after the moſt important of truths—I mean the knowledge of Nature and her laws; for it can ſcarcely be thought poſſible that any rational creature can be unconcerned to know the ſtate of the world about him, or to behold the various phænomena that perpetually obtrude themſelves upon the ſenſes, without being ſtrongly prompted to enquire into their cauſe and nature. And though philoſophy has of late been branded as the cauſe of miſchief by thoſe whoſe intereſt it is to promote ignorance and ſlavery in the world; the wiſe and virtuous know well that there is no enquiry whatſoever more calculated to inſpire every good diſpoſition of the heart, and every uſeful acquirement of the head; that points out a more rational path to a knowledge of the Deity, or more rationally weans the mind from narrow and confining prejudices. In the following Lectures, Nature has been ſet to work in variety of ways, to prove the truth of her own operations; and no aſſent has been aſked to a ſingle propoſition, that was not fairly and openly proved by experiment or obſervation: for our preſent philoſophy but points out the means of interrogating Nature in the way of trial and experiment. This, however, is what gives it the ſuperiority over that of the ancients; for their ſyſtems of philoſophy were built ſo much upon hypotheſis and conjecture, that one ſyſtem has given way to another in ſuch ſucceſſion, that many ſuppoſe ours ſhall give way in due time, and be ſwallowed up in the tide of opinion. But if the approach to truth by the way of analyſis be ſlow, it is ſure: facts command conviction; and, to the glory of our own times, fanciful conjectures fly before experiment, like ſhadows before the ſun. Truth, indeed, is a difficult acquiſition. We find it matter of circumſpection to ſet down any thing as ſuch even in our moſt ordinary affairs; but much more ſo when we dare to inveſtigate Nature; we muſt ſee her, and try her on all ſides, and be *ſure* that ſhe ſtill confeſſes the ſame thing, or it will be more than probable we ſhall deceive ourſelves. Pythagoras is ſaid to have been ſo conſcious of the difficulty of truth, that he would not ſuffer himſelf to be called one of the Magi (one of thoſe oſtentatious names which the learned of his time took upon them)--- No, ſaid he, I am a philoſopher, that is to ſay, I am a lover of, and an enquirer into, truth, rather than one really poſſeſſed of it. Like him the ſcience and its profeſſors affect the ſame modeſty; as knowing, that when we have ſtretched our faculties to the utmoſt pitch, we know but little in compariſon of the immenſity that lies beyond our reach. Yet, neverthleleſs, though our ſcanty enquiries are confined to ſhort limits, and though we can but ſee and reflect upon the ways of Nature imperfectly; it gives an high, it gives a rational delight to the mind even to be loſt in ſuch excurſions; for they teach us to be humble, they teach us to be wiſe; they teach us to be modeſt concerning our own abilities, and to pay a ſuitable adoration to that Being who ſits at the head of theſe things.

A beautiful writer obſerves, that the univerſe may be compared to a book written with ſublime obſcurity! where the author, ſeeming to level himſelf to the capacity of his readers, almoſt perſuades them they nearly underſtand the whole. Happy for us who enter this labyrinth, if we do not miſtake the path! Much has been done in theſe latter ages for the progreſs of the human mind, but little for our ſpecies; much for the glory of man, ſomething for his liberty, but not much for his happineſs. In a few directions our eyes are dazzled with a promiſing light; but thick darkneſs ſtill covers an immenſe horizon. The mind of the philoſopher exults with ſatisfaction upon a ſmall number of objects; but a view of the ſtupidity, the ſlavery, the extravagance, and the barbarity of man, takes off much from that ſatisfaction. The friend of humanity can ſcarcely receive unmixed pleaſure, but by abandoning himſelf to the endearing hope of the future.

It is, however, a pleaſing ſolace to the ſtudious mind, that the great, the liberal, the generous purpoſe of philoſophy, is an attempt to let mankind ſee what Nature is, that they may judge between her works, and the extraneous ſyſtems of art and police. It is the buſineſs of the teacher in phyloſophy (in order that it may have its moral effect), that he have nothing to do with the bitterneſs of ſatire, or the enchantments of the theatre: neither the thunder of eloquence, nor the ſublime of inſpiration, ſhould enter into his diſquiſitions: he ſhould confine himſelf to the ſimplicity of reaſon: he ſhould open the book of Nature before his readers; this ſpeaks an intelligible language to all underſtandings. He ſhould ſhew that the foundation of morality is in the conſtitution of things: he ſhould *ſuppoſe* nothing; but endeavour to *prove* all he inculcates.

In the following work I have endeavoured to follow up theſe ideas, many of which are not my own: I have borrowed liberally, not only the doctrine, but in many inſtances the very words of various authors and experimentaliſts, where I found them more intelligible, or better, than any I could ſubſtitute in their place.

But having been much uſed to arrangement, in order to render my oral lectures plain and ſimple, I hope the reader will find the attention paid to that circumſtance in the following ſheets contribute to the eaſy apprehenſion of the ſyſtem and unity attempted in them. The work having been written at various times, and in various places, tautology has crept into many parts of it; and I fear ſome are more condenſed than they ſhould be in a ſyſtem of familiar philoſophy. Originality, or the pride of diſcovery, has not led me beyond the bounds of what I believe to be truth. The identity of fire, light, heat, caloric, phlogiſton, and electricity, or rather their being but modifications of one and the ſame principle, as well as their being the grand agents in the order of nature; theſe are the leading problems of the work; and the parts which have, in a great meaſure, any pretenſions to novelty. They do not militate againſt the Newtonian ſyſtem; and are preſented to the reader more in the form of queries, than as doctrines fully eſtabliſhed: they do not interfere with the elementary part of the work; or influence thoſe concluſions that have been ſanctified by time and experience. Whether I am right or wrong in my ideas of them, I doubt not but they will have a fair and candid reading. The theory was not ſought, but has obtruded itſelf through an experience of near forty years: and though it differs in many points from the late received and adopted ſyſtem of chemiſtry, my admiration of that ſimple and elegant ſyſtem is not at all diminiſhed; I rather lament that its worthy and ingenious founder did not live to have perfected ſo excellent and promiſing a beginning. It may appear bold, invidious, or like the affectation of ſingularity, to differ from doctrines that are become eſtabliſhed throughout Europe: but I dare do this, and more, when truth is the object. If my opinions are confuted by experiment and reaſon, I will bow to conviction, and be one of the firſt to abandon my theory. I ſolace myſelf, however, with the idea, that in an honeſt and laborious ſearch after truth, right or wrong, nothing is loſt; and probably ſomething may be gained. So comes this work into the world, without a ſtring of capital letters attached to the name of its author. Theſe fortuitous advantages, however, have too little connection with a work of this nature to affect thoſe whoſe good opinion alone I am ſolicitous to obtain. Like others, no doubt, it will be ſinged a little in its paſſage through the ordeal of criticiſm; for poliſhed writing is neither in my power, nor do I think it proper upon a didactic ſubject like this. A ſimple perſpicuity has been my aim; and to be eaſily underſtood my earneſt endeavour. The plates, though not elegant, will, I truſt, be fully explanatory of my meaning: and a copious index will not only point out every ſubject, but the particular parts of each, ſo that they may be inſtantly found. This index is alſo made a dictionary of ſuch uncommon words as could not, without affectation, be omitted in a work of this nature.

CONTENTS

OF THE FIRST VOLUME.

INTRODUCTORY LECTURE,

LECTURE II.

LECTURE III.

leys—Wedge—Inclined Plane—Screw.—On Friction.—On the Windmill.—The travelling Corn-mill.—Experiments to aſcertain the Excellences and Defects of Wheel-carriages; from whence Deductions are made for the Improvement of Coaches, Carts, Waggons, &c.—Experiments on Coaches, Chariots, Curricles, &c.—Experiments to aſcertain the beſt Proportions between the Heights of the fore and hind Wheels, &c.—Experiments to eſtimate what the Draught of Carriages is on different Kinds of Roads, and on different Declivities. Miſcellaneous Obſervations on the Excellences and Defects of Wheel-carriages in general.—Improvements on Wheel-carriages ſuggeſted.

LECTURE IV.

On Acids — Alkalis — Solution — Diſtillation—Sublimation.—On Affinitive Attraction. — Of Combuſtion — Salts —Earths — Metals—Minerals.—Vegetable Analyſis.—On Animal Analyſis.—Chemical Apparatus.—Miſcellaneous Obſervations and Experiments in Chemiſtry.

LECTURE V.

Mechanical Properties of Air.—Chemical Properties of Air.—On Wind.—Air Guns.—Wind Guns.—On Sound.—Sympathy of Sound.

LECTURE VI.

Of Specific Gravities.—Hydroſtatic Balance.—On the Diver's-bell.—On the Syphon.—Conducting Pipes.—Of Pumps.—The Rope-pump.—The Forcing-pump.—Boulton and Watts's Steam-engine, with the Cylinder in the Boiler.

INTRODUCTORY LECTURE,

CONTAINING

SOME GENERAL IDEAS

RESPECTING

THE SYSTEM OF NATURE.

SECTION I.

IN order to explain any art or ſcience, I think it is uſeful to give ſome outlines, or general ideas, of their principles, before particular parts are entered upon. On this account, a very unpopular beginning will be given to this work:—The philoſopher will find ſome documents to condemn, and ſome perhaps to wonder at; the ſtudent will be perplexed before he is inſtructed; and the critic will have plenty of matter for animadverſion, and perhaps for ridicule. But as I ſhall advance nothing but what I believe to be true, and hope to demonſtrate, it will promote the cauſe of truth ſhould any part be confuted.

I ſet out with a perſuaſion, that *attraction and repulſion are the great acting principles of the univerſe*. By *attraction*, I mean that tendency which the atoms of matter have to unite and form themſelves into bodies; and by *repulſion*, the oppoſing reaction of fire, in its combined, active, and latent ſtates; or in its characters of electricity, heat, or light. The experiments, through the courſe of this work, will principally tend to the eſtabliſhment of this perſuaſion; and that light, heat, fire, and electricity, are but modifications of one and the ſame principle.

I conceive the Sun to be the fountain-head of fire in our ſyſtem; and that his light, when it reaches the earth, is only that fire in a greatly rarefied and mixed ſtate; and which therefore, when condenſed by lenſes or mirrors, becomes real fire again. That light is matter, or material, cannot be doubted when we obſerve the inflections it ſuffers in paſſing out of one medium into another, as out of air into glaſs, or out of glaſs into water, &c. That the particles of light repel each other, and fill all ſpace, in a more or leſs diluted ſtate; that they are thrown off, or repelled, from the equatorial parts of revolving ſuns, which are recruited by receiving or imbibing light at their polar parts, from other ſuns; therefore, that light exiſts in the abſence of the luminous body, and is only put into progreſſive motion by it. That (by what will be made probable hereafter) it proceeds from the Sun, elementary, or in the character of electricity; but being obſtructed in its paſſage through an ill-conducting atmoſphere, it mixes with the finer parts of terreſtrial matter and becomes light; and what reaches the earth, unites with the groſſer matter of the earth's ſurface, and becomes culinary fire. We have no conception for what purpoſe the ſun turns on his axis, if it be not to increaſe this repulſion and momentum, by throwing off thoſe particles of light centrifugally from his body, as Plate I. by which they are projected into infinite ſpace in a more and more diluted ſtate, till meeting with light from other ſuns of greater momentum, they mix, unite, and are turned into the ſtronger ſtream. For we ſhall prove the fixed ſtars to be ſuns; that they turn on their axes like ours; and no doubt project their light in the ſame way. See Plate II. fig. 1. So theſe luminaries, diſperſed through ſpace at infinite diſtances from one another, fill the univerſe with light of various colours; ſome projecting a predominance of red, others of blue, and others of white, light. From the great diſtance by which the heavenly bodies are ſeparated, the light of each muſt become feeble before it reaches its neareſt neighbour; and not only be abſorbed into the ſtronger ſtream, but much of it attracted into the body of that neighbour, at its polar parts. For the polar parts of each ſun, having little centrifugal repulſion, its attraction in thoſe parts will draw in vagrant and weak light from other ſuns, and thereby ſupply and recruit continually the quantity thrown off at its equatorial parts. This idea may be rendered more familiar by Plate II. fig. 2, where *a a* repreſents the projected light of the ſun *S*, and *c c* its abſorbed light. Hence no waſte or diminution of light or heat has been obſerved in our ſun; or in the light of thoſe other ſuns, the fixed ſtars. By thus *giving* and *taking*, the whole univerſe is filled with light and motion! For, that a feeble light is capable of being abſorbed, turned back, or retarded, in its motion, by ſtronger light, is evident from the light of the ſtars being loſt in the ſuperior ſplendour of the ſun; and from the feeble light of a common fire being put out, by the light of the ſun. This effect, though ſo common, may not, perhaps, have been accounted for on the above principles. We will therefore familiariſe it by Plate II. fig. 3, where *S*, the ſun, darting his more powerful rays againſt thoſe of the weaker fire *F*, turns them back, and, by oppoſing their emanation, extinguiſhes the fire. Many other examples will occur in the courſe of this work.

As the ſun turns on an axis that inclines only 8° from croſſing the ecliptic perpendicularly, his equatorial, or greateſt centrifugal diſcharge of particles, will be nearly in the zodiac, or track of the planets. May not the planets be turned on their axes by this impulſe of light? I know that this ſuggeſtion ſeems like an attempt to revive the exploded vortices of Des Cartes: but this is not the caſe; his vortex was made in an imaginary ſubtil matter, the exiſtence of which could never be proved. Light can be proved to be real matter; to have motion, and, of courſe, a momentum. Suppoſe *S* the ſun, and *E* the earth, Plate II. fig. 4, and that the lines *a b c d*, &c. repreſent rays of light iſſuing centrifugally from the ſun. A line from the ſun's centre of gravity *s*, to that of the earth *E*, will ſhew the direction in which the two bodies mutually attract each other; or the line in which they would fall together, if no counteracting principle prevented it: that counteracting principle, I hope to prove, is light, fire, or electricity. The equal diſtances of the lines which repreſent the rays, being agreeable to the equable diſtribution of light through the zodiac, it may be ſeen that twice the quantity falls on one ſide of the line of direction *s*, *o*, as on the other, viz. *a b c* and *d*; while *e* and *f* fall only on the contrary ſide of the line of direction. Though this is an exaggerated proportion, yet in all the poſitions in which the earth ſtands to the ſun, during its annual revolution round him, it will be found that more rays fall on one ſide of its axle and centre, than on the other. If a ball, therefore, ſuſpended in infinite ſpace, without friction, or reſiſtance to motion, have a greater impulſe on one ſide than the other, it muſt turn on its axis. It is true, the momentum, or moving force, of light, has been found to be ſo ſmall, as to ſeem inadequate to ſuch an effect. A ſmall wire balance, nicely ſuſpended on a point, having a ſquare inch of thin latten fixed at one end, was covered by the receiver *c*, Plate III. fig. 9, it was a little more than counterbalanced by a ſmall ſhot, which reſted on the projected plane *a*. The focus of a lens fourteen inches diameter, and twenty-ſix inches focus, being directed upon it, the balance ws inſtantly put in motion; and the ſhot lifted from the plane. The receiver being cloſe, *this* could not ariſe from the motion of heated air: but leſt that ſhould have been the caſe, I had the air exhauſted on the air-pump, and on applying the lens as before, the effect was the ſame. I then balanced one hundred pieces of horſe-hair, each piece of the ſame length, on a nice beam, with one grain: one of theſe hairs lifted the ſhot: ſo that the impetus of light on one and a quarter ſquare foot of the earth's ſurface, may be conſidered as equal to one hundredth of a grain: and by calculation equal to twenty tons on the whole diſk of the earth. Mr. Mitchel, indeed, made the ſame experiment, with great care and addreſs, with a concave mirror of three ſquare feet ſurface, and calculates the momentum of light on a ſquare foot of the earth's ſurface to be no more than the one thouſand eight hundred millionth of a grain. The experiment in both caſes is of too delicate a nature to draw any deciſive concluſion from, except that light certainly has a momentum or moving force.

If light concentrated in the focus of a large burning-glaſs can put a ſmall balance into motion, or move a needle ſuſpended by a magnet; or influence the tail of a comet, ſo as to force it always oppoſite the ſun; and, what is ſtill more ſtriking and demonſtrable; make a pellicle of gold, molten in the focus of a large lens, turn on its axis, the ſame way with the earth's diurnal motion, all the time the focus is kept upon it (ſee Optics):—May not its aggregate momentum be a balance to the earth's gravity towards the ſun? and may it not be natural to ſuppoſe the earth's diſtance from the ſun was determined by the balance of thoſe two powers?—analogous to bodies on the earth, which have their tendency to abſolute ſolidity, counteracted by the repulſive power of light or fire, with which every body on the earth's ſurface is more or leſs united. But this is not all. If the impulſe of light be greater on one half of the earth than on the other, may not this alſo account for its annual motion round the ſun, to produce the ſeaſons? To prove that a diurnal motion, ſimilar to that of the earth, may be produced by a centrifugal ſtream of air, I fixed in a circular box the arms *a b c*, &c. Plate II. fig. 5, turning on the centre *n*: theſe arms were of thin boards, and the box was cloſe, except at the holes *s s* to let the air in, and at the funnel *g* to let it out. A thin glaſs globe was hung by its centre *m* perpendicularly to the machine, by a fine thread. The arms being now turned ſwiftly round by the handle *r*, a current of air flows through the funnel *g*, and the globe begins to turn round without being puſhed away. This I conſider as ſimilar in one fluid to what it may be in another; and a power capable of producing a circular motion. But to give the ball both diurnal and annual motion, by a centrifugal current of air, I made the circular wooden box, Plate II. fig. 6, with oblique holes through its ſide. This box being cloſe at top and bottom, there was only the hole *a* to admit the mouth of a double-bellows to make the current of air equal. The glaſs ball was hung by a very long thread, exactly over the centre *a*; this gave it a conſtant tendency towards that centre, naturally repreſenting the gravitation of planets toward the ſun. The ball being now placed by the ſide of the box, and the bellows blown, the ball inſtantly began to turn on its axis, and deſcribe an oval circuit round the box. This oval circuit was more than I expected; I had therefore the oblique holes bored very true, ſuſpecting that an inequality in them might occaſion this inequality in the circuit:

ſtill it was elliptical. Conſidering that the ſun's axis inclined 8° from a perpendicular to the plane of the ecliptic, it was evident that if ſolar impulſe was the cauſe of the earth's annual and diurnal motion, it muſt be leſs in one part of the earth's circuit than another, and of courſe produce an oval rather than a circular motion. I had the plane of the ball's orbit inclined 8 degrees to the level of the box, and ſtill the oval circuit was invariably produced, as it is in nature, viz. at the place where the ſolar ſtream muſt be moſt powerful, i. e. when the earth is in the middle of it, near the time of the ſolſtices; for the plane of the ſun's equator cuts the ecliptic about the eighth degree of cancer, and the eighth degree of capricorn: and near theſe were the aphelion and perihelion of the ball, or its fartheſt and neareſt diſtance from the repelling box. It may ſeem, that as the ball paſſes the middle of this ſtream twice in one circuit, it ſhould have two diſtant and two near approaches to the repulſive box. No: it ſtill deſcribes equal areas in equal times, and conforms to the law diſcovered by Kepler, that *a two-fold projectile force balances a four-fold power of gravity.* In Plate III. fig. 8, this idea may be made more intelligible. Let *S* be the ſun in one of the foci of the earth's oval orbit *A B*, with a rotation conceived on his axis from eaſt to weſt, in twenty-five days; and on an axis inclined 8° from a perpendicular to the plane of the ecliptic: this axis inclining towards the tenth degree of libra, or towards the point *r*; all which is agreeable to obſervation: the plane of the ſun's equator, therefore, will croſs the plane of the ecliptic near the perihelion and aphelion of the earth's orbit; or, in other words, in thoſe two parts of the orbit which are the neareſt and fartheſt from the ſun, as *s* and *u*: for theſe two points are not at *t*, where the ſun enters ♑ at mid-winter; or at *w*, where the ſun enters ♋ at mid-ſummer; for the earth is not come to its neareſt diſtance from the ſun on the 21ſt of December, nor to its greateſt diſtance on the 21ſt of June, but about eight or nine days later. The earth, therefore, croſſing the ſolar ſtream at thoſe two critical places, viz. at *s* and *u*, muſt have its orbit and motion affected by it. The manner in which the plane of the ſun's equator croſſes the ecliptic, may be better underſtood by inſpecting Plate II. fig. 7, where *s s* repreſents the plane of the ecliptic, and *u u* a plane paſſing through the ſun's equator; ſo *t* may repreſent the ſun's axis, and the angle of 8° it makes with a perpendicular to the ecliptic, *n*. By a ſection of this ſtream, as Plate II. fig. 2, a clearer idea of this hypotheſis may be conceived; where the planet *a* is in the middle of the ſun's equatorial ſtream, and of courſe impelled to its aphelion or greateſt diſtance. But in the ſituations *d d*, it is but partially immerſed in it; here the ſun's attraction will, in a degree, overcome the repulſion of light, and draw the planet to its perihelion or neareſt diſtance.

The zodiacal lights, ſeen at the equinoxes, are alſo a proof that the earth croſſes a ſtream of more than uſual light at thoſe times; and as all the planets move in this equatorial ſtream more or leſs, may not their diſtances, motions, and eccentricities, be thence accounted for? The earth moves the ſwifteſt when it croſſes the ſtream at the winter ſolſtice *g*, and gradually ſlower and ſlower, till it reaches the ſummer ſolſtice *a*; ſoon after which it again croſſes the ſtream, but from its greater diſtance from the ſun, and the ſlowneſs of its motion, an acceſſion of inertia or retardation has taken place, that is not eaſily overcome by an increaſing impulſe. The ſtream alſo is weaker, as being farther from the ſun than at the winter ſolſtice. Hence the effect of this tranſit accelerates the motion of the earth but ſlowly: but aided by the increaſing power of gravity, as it approaches the autumnal equinox, it acquires the acceleration neceſſary to make a two-fold power of centrifugal tendency to balance, or rather overcome, a four-fold increaſe of gravity. This motion in the planets ſeems not even yet to have come to a perfectly ſtanding medium; and it ſeems moſt unequal in the moſt diſtant planets: Jupiter, according to Caſſini, is accelerated half a ſecond per year; and will be near 2000 years before he comes to the utmoſt of that increaſed motion; when he will become retarded like an overſwung pendulum, and meliorate in time to perfect equality of motion. Appealing to the fact in nature, and as may be ſeen deſcribed in any ephemeris, this acceleration and retardation is perfectly agreeable to the motion of the earth, and to that of the other planets, viz. that they deſcribe equal areas in equal times, fig. 8*, Plate III. for all the ſpaces *a b c d*, &c. are equal to one another; the earth travelling from *o* to *p* in January, and only from *q* to *z*, in the ſame ſpace of time, in June. But if a thread could be carried with it, whoſe end was fixed at the ſun's centre, it would paſs over the ſame quantity of ſpace, in the ſame time, in all parts of the orbit. This is not matter of conjecture, it is confirmed by the moſt accurate obſervations, and noted in the Ephemeris, for every ſix days throughout the year, for many years paſt and to come. In fig. 8*, Plate III. it is only noted for the beginning of every month, viz. that the ſemidiameter of the ſun on the firſt of January, as meaſured by a good micrometer, is 16′. 19,2″; but on the firſt of July, it is only 15′. 46,9″. Why appears the ſun leſs in July than January? All objects diminiſh in perſpective, as we recede farther from them; and we are nearly one thirtieth of the ſun's mean diſtance from the earth nearer to him in January than in July. The hourly motion of the earth, in its orbit on the firſt of January, is 2′. 32, 9″; on the firſt of July it is only 2′. 23″: ſee fig. 8*, Plate III. Why does the earth move faſter in January than in July? Becauſe its near approach to the ſun increaſes its velocity; and it is alſo in the middle of the zodiacal ſtream at that time. But to come more immediately to the point, let us uſe the very agent we conceive to be uſed by nature to produce theſe effects, viz. Light, or rather its principal ingredient Electricity. Stick a ſmall needle, *a*, fig. 15, Plate IV. in the light pith or glaſs ball *b* (there being generally a ſmall hole in an hollow glaſs-ball, into which if a piece of cork be fixed, and the needle ſtuck in it, they will both hang by the magnet *m*). If the metallic point *p* (being part of the prime conductor of an electrical machine) be electrified, an aura, *c*, will iſſue from it, that will give the ball *b* a *diurnal motion.* The magnet here is only uſed becauſe it has leſs friction than a ſmall thread.

To produce both annual and diurnal motion by the ſame cauſe, let a ſmooth braſs-ball *a*, fig. 16, Plate IV. have the wire *b* ſcrewed into it, after it has paſſed through the collar of leathers *g*: on the outer end of this wire is fixed the pulley *n* and knob *m*. The ball *z* is of hollow glaſs, with patches of tin foil ſtuck on it to repreſent the eaſtern and weſtern continents of our globe; it reſts on the point of the wire *i i*, which paſſes eaſily through its bottom; this wire is bent as in the figure, and is ſuſpended on the perpendicular needle *e*, fixed in the ſtand *u*: the globe *z* is balanced by the ſhot *s*, ſo that the whole may turn eaſily on the point *c*. The ſtand *u* ſhould be inſulated, by reſting on a ſmall glaſs tumbler, or feet, ſo that when the ſun *a* is electrified by the knob *m* touching an excited conductor, the eclectricity may ſtream from *a* to *c*, and electrify the ball *z*, and the wire which ſuſtains it. To imitate the ſun's motion on his axis, a grooved wheel like *n* (but larger) is fixed at a diſtance, round which, and the wheel *n*, there paſſes a tight ſilk cord, ſo that the pully *n* and ball *a* may be turned with any degree of velocity; this motion and electricity being excited together, *the ball z begins to turn on its axis*, and *revolve round the ſun a*.—This apparatus is incloſed in the receiver of an air-pump, to ſhew that theſe motions take place in vacuo, as well as in the air.

As I conceive the diſtances of the earth and planets from the ſun to be in a ratio determined by their denſities and quantity of ſurface, *i. e.* that a rare body with a large ſurface may be impelled farther from the ſun, than a more denſe body with leſs ſurface; and therefore Jupiter and Saturn, thoſe large bodies, are ſo much more diſtant from the ſun than the Earth, Venus, and Mercury: let *S*, fig. 17, Plate IV. (a gilt or metallic ball) repreſent the ſun, and be inſulated on the ſolid glaſs ſtand *m*; and the light balls *a*, *b*, *c*, &c. be of various ſizes and denſities, agreeable to that of the earth and planets: theſe balls hanging by ſmall ſilken threads centrally over the ſun, will all tend towards his centre, cling round him, and naturally repreſent the power of his attraction. If now the ſun be electrified, by the chain *w* (communicating with the prime conductor of an electrical machine), the balls *a*, *b*, *c*, &c. will be diſperſed according to their denſities and quantity of ſurface, and aſſume diſtances proportionate to that of the earth and planets.

SECTION II.

On the Influence of the Sun's Motion on the Earth and Planets.

IT may ſeem a little contradictory that the ſun ſhould both attract and repel. I conceive the light of the ſun to be merely his atmoſphere;—an ocean of fluid fire that ſurrounds him, whoſe particles repel each other, and are the cauſe of repellency and elaſticity in all other matter. But the body of the ſun attracts like all other bodies, is a ſolid nucleus, perhaps black, and covered but thinly with his repulſive atmoſphere; inſomuch, that, by great emiſſion, ſome parts of that body may be left bare, and cauſe thoſe black ſpots ſo frequently ſeen on his face. Thoſe ſpots have always a duſky ſhade round them, and appear hollow and indented when they paſs over the edge of the ſun;—circumſtances favourable to this opinion. By them we learn, that the ſun turns on his axis in twenty-five of our days and ſix hours. That this equatorial emanation from the ſun muſt diminiſh in its force by diſtance (perhaps as the ſquare of that diſtance) is probable, from the neareſt of the planets, Mercury and Venus, being thrown much farther out of the plane of the ecliptic than the ſuperior planets, Mars, Jupiter, Saturn, and the Georgian planet. The inclination or greateſt latitude of Mercury being $7^{D.}$ $0^{M.}$ $0^{S.}$

Venus - - -	3	23	35
Mars - - -	1	51	0
Jupiter - -	1	18	56
Saturn - - -	2	19	50
Georg. Sid. -	0	46	20

Now as the greateſt diſtance, north or ſouth, that any planet departs from the plane of the ecliptic, is not more than ſeven degrees, and as the ſun's inclination to that plane is eight degrees, it ſeems to follow, that all the planets of our ſyſtem muſt be more or leſs immerſed in his equatorial emanation; and that it is that ſtream that keeps them in their orbits. Not that we conceive, that it is only from his equatorial parts that light is projected; it muſt be alſo projected from the regions towards his poles, but certainly not with the ſame vigour. If a large hollow globe, perforated with numberleſs little holes, were filled with water, and turned ſwiftly round, water would fly from all parts of it, no doubt centrifugally; but, certainly, from its equatorial parts with the moſt force: ſo light comes to us from all parts of the ſun, or otherwiſe he would not appear round. A pleaſing repreſentation of this attraction and repulſion may be made in a jet of water. *b*, fig. 13, Plate III. is the ſpouting pipe, and *a* a ſmall wooden ball immerſed in the jet. This ball will turn on its axis like a planet, and preſerve its ſituation for a long time, if the jet be equal: the jet repreſenting the repulſive power of ſolar light; and the tendency which the ball has to fall, the influence of attraction. A ball was made oblate (or like an orange), to repreſent the earth and Jupiter; when it was immerſed in the jet it immediately turned its protuberant ſide towards the ſtream, and revolved in that direction. But to come nearer to the point, let the pipe *b* be a ſharp metallic point ſtuck perpendicularly on the prime conductor of an electrical machine: when the machine is in motion, if a ſmall pith-ball be gently dropped on the point, it will be inſtantly raiſed above it, and turn round by the electric aura like the ball *a*.

It is an excellent rule in philoſophiſing, to admit no more cauſes than what barely account for the phænomena under examination. If in the courſe of this work it can be proved that light, fire, caloric, phlogiſton, electricity, &c. are but modifications of one and the ſame principle, viz. electricity, the difficulties attendant on our reſearches into nature will be greatly reduced.

The materiality and momentum of light being proved, may not the motions and diſtances of both the planets and their ſatellites be rationally accounted for mechanically?

If, for inſtance, the planet Jupiter be made of materials ſpecifically lighter than thoſe of the earth (which the ſwiftneſs of his motion on his axis ſtrongly indicates), his gravity towards the ſun would be leſs, in proportion to his quantity of matter; and from his greater ſurface he would be more repulſed by the ſtream of light; and therefore thoſe two powers would not balance each other, but at a much greater diſtance than the earth is from the ſun. Saturn is alſo next to Jupiter in ſize, and therefore ſubject to great repulſion; from whence may ariſe his rapid rotation on his axis, and his ſtill greater diſtance from the ſun. The ſmaller planets are all nearer to the ſun, and muſt have greater denſity and ſolidity to bear the heat incident to their ſituation; of courſe their gravity will combat a ſtronger repulſion; and they will be drawn nearer to the ſun before the balance between thoſe two powers will be affected.

Mars being our next neighbour, he has many coincidences with the earth: he turns on his axis in nearly the ſame time; that axis inclines like that of the earth; and his orbit croſſes the ſolar ſtream near the ſame places with the earth. This laſt coincidence, probably, occaſions the other two. As the materials of which he is formed appear to have a chemical rejection to red light (which ſeems the cauſe of his duſky red appearance), that part of light being the moſt powerful of any of the ſeven colours of which light conſiſts, why may he not have ſo much more impulſe from red light than from the green light, which our globe rejects, as to make their diurnal motions nearly alike, and balance his greater diſtance? for Mars is ſituated one third farther from the ſun than the earth.

Treating here of general matters (to give an elementary idea of this hypotheſis), the details and particulars muſt be poſtponed. The planet Jupiter revolves on an axis nearly perpendicular to the plane of the ecliptic; being therefore in a more diffuſed and diverging part of the ſtream of light than the inferior planets, both attraction and repulſion will act more equally upon his body than if he were nearer, and more expoſed to the firſt impulſes of the ſolar ſtream: hence his eccentricity is leſs, his motion more equal, and his oblate equatorial protuberance more immediately in a line with the two powers of attraction and repulſion, than that of any other planet.

The oblate protuberance of the earth lies oblique to the two influences, particularly at the ſolſtices. Muſt not the ſolar impulſe, therefore, be greater in ſummer on our northern hemiſphere, than on the ſouthern? and, in winter, greater on the ſouthern, than the northern hemiſphere? and thus force the earth's axis progreſſively more and more towards a perpendicular (as is well known to be the caſe), and produce the preceſſion of the equinoxes? Theſe effects may be better underſtood by an inſpection of fig. 12, Plate III.

where the ſouthern hemiſphere *s*, of the earth *c*, will be found more immerſed in the ſolar ſtream than the northern: and in ſummer, when the earth is at *a*, the northern hemiſphere *n* will partake of both the influences more than the ſouthern. Muſt not theſe inequalities alter the poſition of the earth's axis, and make it recede farther and farther from its direction to the polar ſtar, as is known to be the fact? and if ſo, muſt not the plane of the earth's equator cut that of the ecliptic progreſſively more and more towards the weſt, in the contrary order of the ſigns, and thereby produce the preceſſion of the equinoxial points?

As the impulſe of light muſt be greater upon the earth and planets in perihelion than in aphelion (or at their neareſt than their greateſt diſtance), of courſe the earth, by moving in its orbit ſlower in ſummer, will have its meridians come ſooner to the ſun every day than in winter; and account for the nearer approach to equality of apparent and equated time in ſummer than in winter; which is alſo the fact.

Theſe phænomena, I preſume, may be as rationally accounted for by the theory of impulſive light, as from that of centripetal and centrifugal forces. For though, by both theories, the earth muſt move ſwifter in perihelion than in aphelion, the diurnal motion is not at all accounted for by the latter theory *. Now if (as has been proved) there be a greater impulſe on one ſide of the earth than on the other;—and *that* alſo agrees with the way it actually revolves,

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* For Sir Iſaac Newton ſays in a letter to Dr. Bentley, "If the ſun, by his rays, "could carry about the planets, yet I do not ſee how he could thereby affect their diur- "nal motion."

viz. from the weſt to the eaſt;—and if the impulſive momentum is leſs in aphelion than in perihelion, it follows that not only the earth's annual progreſs in the ecliptic muſt be retarded, but alſo its rotation on its axis. For, though the proportional difference between the impulſe of light on one ſide and on the other, muſt be the ſame at whatever diſtance, yet the ſum of the two impulſes will be leſs at a greater, than at a ſmaller diſtance; and account for ſolar and ſidereal time being nearer equality in ſummer than in winter, and that the diurnal rotation is alſo ſomewhat ſlower.

Theſe obſervations are advanced here only to give a general view of that important principle, light. But it muſt not be conſidered yet as in either an aſtronomical or optical point of view. Theſe two ſubjects will be ſeparately treated at large. We ſhall now conſider light or fire in the various effects it produces, in uniting, forſaking, decompoſing, or rarefying bodies, here on earth.

SECTION III.

On Fire *.

IN the order of nature we find oppoſing or antagoniſt principles in a ſtate of perpetual warfare. The centrifugal tendency of the

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* "Man alone, of animals, can enjoy equally the day and the night; he alone can bear to live within the torrid zone, and upon the ice of the frigid. If certain animals are partakers with him in theſe advantages, it is only by means of his inſtructions, and under his protection. For all this he is indebted to the element of *fire*, of which he alone is the ſovereign lord. God has intruſted the firſt agent in nature to that being alone who, by his reaſon, is qualified to make a right uſe of it."

St. Pierre, Stud. 1. vol. 1. p. 62 and 63, of *Hunter's Tranſ.*

planets is ſaid to be a contention with the centripetal force, that never ceaſes for a moment; for Nature never ſleeps. The ſun makes war upon the inertia of the earth; and, in ſpite of its ſluggiſh nature, makes it to turn on its axis, perform its annual journey, and to bring forth trees, fruit, and flowers. Every animal muſcle has its antagoniſt muſcle: paſſion is checked by reaſon *: and no two enemies are more inveterate than heat and cold, action and reaction, buoyancy and gravity, &c. &c. But of all oppoſing or antagoniſt principles, none exhibit ſo general an enmity as fire and attraction. Theſe two enemies are in a ſtate of unceaſing warfare: attraction drawing the particles of matter into a cloſer and cloſer union; while fire (or caloric, in the language of modern chemiſtry) is ſtill ſtriving to ſet thoſe particles more and more at a diſtance. Hence it is ſaid, that heat expands all bodies, and that cold contracts them; that is, cold aſſiſts attraction in overcoming the repulſive power of fire: for we do not conſider cold as an agent or a body, it is but a name we give the abſence or ſuppreſſed power of fire. Not that we conſider fire as *totally* abſent, or ſuppreſſed, even in the coldeſt bodies; for poſitive cold, or a total abſence or abſtraction of fire, cannot be proved to exiſt in nature.

Whether fire, light, and electricity, are modifications of one and the ſame principle, will be conſidered hereafter; at preſent we ſhall only inveſtigate its property of expanding all bodies it attacks, or is united with. 1ſt. An iron bolt that would eaſily paſs through a ring, will ſtick faſt in it after being heated a little in the fire. 2dly. If the bulb *a*, fig. 24, Plate V. be half filled with ſpirits of wine,

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* For reaſon may be conſidered as repulſion, while paſſion perſonates attraction: ſo the material and mental world exhibit analogy.

tinged with cochineal, and graſped with a warm hand, the air *b* will ſwell and preſs the liquor up the tube *d*, ſo as to make it run out at *c*. 3dly. Quickſilver is peculiarly ſuſceptible of expanding by heat and contracting by cold, and is therefore uſed for thermometers. *a*, Fig. 14, Plate III. is a bulb blown at the end of a glaſs capillary tube, which is open at *b*; if the bulb *a* be heated nearly to redneſs, the air will be ſo expanded as to leave the bulb *a* a vacuum; if then the end *b* be dipt in quickſilver, the preſſure of the atmoſphere will force the quickſilver into the bulb, and fill both it and the tube *c*. If the bulb now be wet, and expoſed in a froſty night, ſo that the water be frozen, the quickſilver will fall down the tube to *d*, which is called the *freezing point*, and where it muſt be ſo marked on its ſcale. The bulb is then expoſed a few minutes in boiling water; this will make the mercury riſe to *g*, where another ſcratch muſt be made on the ſcale, which is called the *boiling point*. We are now in poſſeſſion of a ſcale for all the degrees of heat, from ice to boiling water; (when the water boils, no increaſe of fire can make it hotter in an open veſſel). The ſpace between *c* and *d* muſt now be divided into one hundred and eighty equal parts, and thirty-two more of the ſame diviſions continued below the freezing point, if the tube will admit of it: ſo that *o* is extreme cold; thirty-two, the freezing point; fifty-five, temperate heat; ſeventy-ſix, ſummer heat; ninety-eight, blood heat; one hundred and twelve, fever heat; at one hundred and ſeventy-ſix ſpirits boil; and at two hundred and twelve water boils. This is called Fahrenheit's ſcale, from the name of the inventor.

Fourth, The pyrometer is an inſtrument for meaſuring the proportional expanſion of different metals by the ſame degree of heat. Bars of different metal, of the ſame length and thickneſs, are expoſed in boiling water, fixed at one end, but operating on micrometers, or multiplying wheels, at the other, by which an index ſhews the proportional expanſion between one metal and another.

1. White glaſs barometer tube	100
2. Hard ſteel	147
3. Iron	151
4. Copper	204
5. Braſs	232
6. Fine Pewter	274
7. Grain Tin	298
8. Lead	344
9. Zinc	353

So zinc has the greateſt, and glaſs the leaſt expanſion, by the ſame degree of heat.

Fifth, *a* and *b*, fig. 18, Plate V. are two glaſs bulbs united by the tube *c*, and balanced on a point, *d*. This apparatus ſtands before a ſheet-iron caſe that holds two hot heaters, *n* and *o*. In *a* is contained a red-tinged quantity of ſpirits of wine; and the ſpace *b* is devoid of air, or a vacuum. When *a* is near the heater *n*, the liquor in it will be rarefied into ſteam, which riſing to the top of the bulb, forms ſuch a reaction on the ſurface of the fluid, as forces it up into the bulb *b*, which ſoon becomes heavier than *a*, and it falls down to *o*; then are the ſpirits of wine forced up into *a* as before, and ſo on alternately: this force and action may be made to work two pumps, *r* and *s*. But the intention of the experiment is to ſhew the repulſive force of active fire; for *b* being lifted out of the power of the heater *o*, and *a* expoſed to the action or heat of *n*, the two ends riſe and fall alternately, becoming levers to work the pumps, *r* and *s*.

Sixth, The æolipile is another inſtrument to ſhew the repulſive power of fire: it is a large copper ſphere, with a ſmall tube (almoſt capillary) joining to it, ſee fig. 19, Plate V. at *a*. This veſſel being a little heated, and its tube immerſed in water, or ſpirits of wine, the preſſure of the air will ſoon force the fluid into it. If then it be placed over the carriage fire *d*, the ſteam will be ſo violently forced out of the tube *c*, that by the reaction given to it by the air, the whole carriage will be forced backwards in the direction *g h*.

Seventh, If a glaſs bulb, fig. 20, Plate V. be filled as above with ſpirits of wine, and inclined by the handle *b*, ſo that the ſpirits do not cover the end of the ſmall pipe *d*, while a candle rarefies the ſpirit: and if then the handle *b* is lifted up, ſo that the ſpirit covers the end of the pipe *d*, the fluid will be forced through the candle *c*, ſo as to produce a caſcade of fire, projected to a conſiderable diſtance. What is this, but the fluid rarefied into ſteam by heat, ſwelling, and thereby preſſing the fluid through the pipe *d*?

SECTION IV.

On the repulſive Power of Fire.

THE ſun acts upon the inert matter of our globe; and, by heating its ſurface, makes even blocks and ſtones ſwell by day, and cold contracts them by night. Its active fire, uniting itſelf to water, aſſiſts the riſe of vapour, and repleniſhes the atmoſphere with rain. Heat qualifies all menſtruums to diſſolve the matters to which they have affinity with additional powers:—ſalt, ſugar, tea, reſins, wax, &c. diſſolve in hot fluids, much eaſier than in cold. Fire is the moſt powerful agent in the decompoſition of bodies. It is the only eſſential fluid in nature, and the cauſe of fluidity in other bodies, by ſeparating their parts: for, as bodies become fluid by the application of fire, ſo fluids preſerve their fluidity by the fire they contain. Hence even air itſelf might become ſolid, if deprived of the caloric, or fire, it contains; as bodies of the moſt difficult fuſion become fluid, when penetrated by a ſufficient quantity of the particles of fire. All bodies become hot, by the approach of ignited bodies and by friction: we find, however, that light, heat, and the electric fluid, have ſo many properties in common with fire, that we ſcruple not to think, and hereafter hope to prove, they are all but modifications of the ſame principle. Rubbing, or friction, in *all* bodies, produces heat and electricity; and both theſe dilate bodies, help vegetation, germination, evaporation, motion of the blood, the growth of the fœtus, and the hatching of eggs. Heat and electricity both reduce and melt bodies; and bodies that receive heat with difficulty, receive electricity ſo, &c. Is it not more than probable, that the rays of the ſun are diluted fire (nay, perhaps, electric fire)? May not the velocity with which they proceed from the ſun prevent their abſorption by the air, in their paſſage through it? for perfectly tranſparent bodies receive no heat from ſolar light. And as all bodies have more or leſs affinity to fire, may not this dilated fire be abſorbed by various bodies, and lie in union or a concrete form in them, till called forth from them by friction, combuſtion, or ſtronger affinity? Experiments that favour this hypotheſis are: 1ſt. Rays collected in the focus of a burning-glaſs, produce, on opaque bodies, the moſt intenſe heat. 2d. Living vegetables imbibe light (as nutrition) from the air, and part with it back again into the air, in the act of combuſtion, boiling, or putrefaction (for rotten wood, putrid fiſh, the ignis fatuus, indeed all animal and vegetable ſubſtances, are luminous while decompoſing by putrefaction); which is but parting with the inflammable principle, that was a conſtituent part of theſe bodies while in health. 3d. Bodies in the act of delivering fire to the air, or any other affinitive menſtruum, are univerſally hot; hence the heat of a common fire, inflamed gunpowder, &c.—the heat of effervеſcent mixtures, ſuch as diluted vitriolic acid and iron filings—copper and diluted nitrous acid—iron filings, water, and ſulphur, &c.

This principle (called caloric in the new language of chemiſtry) is the grand antagoniſt of the attraction of coheſion. Theſe two oppoſing powers keep nature in a ſtate of perpetual motion. When the attractive force is ſtrongeſt, the body continues in a ſtate of ſolidity; but if, on the contrary, heat has ſo far removed the particles of it, as to place them beyond the ſphere of attraction, they loſe their adheſion, and the body becomes fluid. Water, when cooled below 32° of Fahrenheit's thermometer, becomes ſolid, and is called ice. Above that temperature, its particles not being held together, it becomes liquid; but when raiſed to 212°, its particles give way to the repulſive power of fire, and, flying off, aſſume an aëriform ſtate, called ſteam: the ſame may be affirmed of all bodies in nature. But as no veſſel can contain this ſubtle fluid, as it eſcapes through every thing, it is difficult to define it but by its effects: the preſſure of the atmoſphere checks it in part, and prevents fluids from flying off, in ſteam or gas, along with it. By furrounding bodies, and being interſperſed among the particles of bodies (according as thoſe particles are arranged or diſpoſed by that polarity which takes place when a body paſſes from a fluid into a ſolid ſtate), the body is ſaid to have a capacity for receiving, retaining, or parting with fire. When this repulſion overcomes the adheſion of fluids, and the preſſure of the atmoſphere, the fire flies off with the vapour, and the fluid is cooled: hence the cold produced by evaporations of all kinds, ether, beer, &c. when in an exhauſted receiver, ſinks the thermometer. Spirits of wine boil in vacuo, by the heat of the hand, producing intenſe cold. Snow and ſea-ſalt, mixt, attract heat from neighbouring, or touching, bodies, producing ice in an hot room; and by Glauber and ammonical ſalt, with ſpirit of nitre, quickſilver may be frozen into a hard metal. Hence we ſee why fire, going into a latent ſtate, produces cold; and, into an active ſtate, heat: why the blood, in an healthy ſtate, retains the ſame heat in cold and hot weather. For evaporation cools both the earth and the human body.

All elaſtic bodies are combuſtible. Is not fire, therefore, the cauſe of elaſticity? Fire in all bodies, and added to all bodies, increaſes their elaſticity. Why do corks fly out of bottles of liquor ſtanding near the fire? Why do veſſels nearly full of any fluid boil over when ſet on an hot fire? Why do the ſtraight bars of a fire-grate crack and make a noiſe as if ſomething was breaking all the while the fire is increaſing, and alſo when it is diminiſhing, but expanſion and contraction? What makes an harpſichord riſe in its pitch in a room without a fire; and fall below the pitch, when a fire is in it? Why do the back and leaves of this book bend when I read by the fire? Why are my bones more liable to break in cold froſty weather, than in any other kind of weather? Why does my new ſhoe pinch me when I ſit by the fire? Why does a roll of brimſtone crack and break by only holding or graſping it in my hand? Why is the iron-hoop of a tub put on when it is hot, but that it may hold faſter when cold? When you ſtand before the fire, why ſhould the watch and money in your pocket become hot, while the pocket is cool? Why does water chryſtallizing in froſt, burſt containing veſſels? high-roads? trees? pipes? ciſterns? nay, even rocks? Theſe, and a thouſand more inſtances may be adduced to prove that heat *expands* all bodies, and cold (or the diminution of heat) *contracts* them: for the ſwelling of water, when freezing, is no contradiction to this doctrine: for water in the act of chryſtallizing incloſes more pores or ſpaces than in its fluid ſtate, and of courſe burſts the containing veſſels, &c.

Why am I warmed by ſitting cloſe to the fire? or, why is the air near the fire hot, when the air is known to be a bad conductor of heat, and neither to receive or retain it but with conſiderable difficulty and reſiſtance? Fire in the air is latent till put into motion by active fire, ſuch as burning coals, wood, candles, &c. Emanating particles of fire repulſed from theſe, excite the latent fire in the adjoining air, and put it in motion, thereby making it become ſenſible heat. This excites in my body the already active fire to a greater degree of activity, and gives me an *higher ſenſe* of heat than is natural in a cool atmoſphere. Hence a ſort of warfare takes place near a fire, the emanating particles of which are puſhing from the fire, while the colder and heavier air is perpetually puſhing towards it. Hence alſo the reaſon why the greateſt heat produced by a fire is immediately above it, in a chimney, becauſe there the current of air and the current of fire are both in the ſame direction. Earthen pipes therefore placed above a fire (as in my patent-ſtove), ſeparate the heat from the ſmoke, and ſend the air that paſſes through them into a room hot, and unpolluted by paſſing through metal pipes.

Thus fire, like the other parts of nature, is perpetually ſtriving at an equilibre: it cannot be confined in any body while that body touches, or is in the neighbourhood of, colder bodies, but it will ruſh out by its natural elaſticity to join the colder body, till both become of the ſame temperature. This effect takes place in vacuo as well as in the open air. The only way therefore to confine fire is, to ſurround it with bodies that are hotter than that body with which it is united.

SECTION V.

On latent Fire.

FIRE going into a latent ſtate, may be repreſented as proceeding from a circumference to a centre, as *a*, fig. 21, Plate V. or, as electricity paſſing out of a natural into a negative ſtate. And fire going into an active, from a latent ſtate, may be repreſented by *b*, as an emanation proceeding from a centre to a circumference, and alſo as electricity growing poſitive: for all bodies throwing out elementary fire are *hot*; abſorbing it, *cold*.

Some things in nature have better capacities for receiving fire, uniting with it, or conducting it, than others. If I put the end of a rod of glaſs, and a rod of iron of the ſame length and thickneſs, together, into the fire, the iron, at its oppoſite end, will ſoon become too hot to hold, while the glaſs will betray no ſigns of heat. We ſay, then, that iron is a better conductor of heat than glaſs. 2d. I take a piece of iron in one hand, and a piece of wood in the other; the iron feels cold, and the wood warmer: I try their temperature by the thermometer, and find them both of the ſame heat! How is this?—The iron has a ſtrong affinity to fire, conducts the fire from my hand much ſwifter than the wood, and hence gives me a more lively ſenſe of cold. 3d. I take up a warm poker in one hand, and the piece of wood in the other: the wood now feels colder, becauſe my hands are warmer than the wood, and colder than the iron; the iron is, therefore, in the act of communicating an additional quantity of fire to my hand, and the wood depriving it of a portion of its natural quantity: for all nature ſtrives at an equilibrium, while the great agents, fire and attraction, are continually at work to deſtroy or diſturb it. 4th. Why do I clothe myſelf in wool?—Becauſe it is a bad conductor of heat, and retards its eſcape from the body. I make myſelf a muff of fur, becauſe it is ſtill a worſe conductor of heat than wool. For ſheep are natives of a temperate climate; but bears and ermine of the coldeſt:—hence we find the clothing of animals in the torrid zone, hair—in the temperate zone, wool—in the frigid, thick fur. Linen conducts heat much better than wool; and hence its coldneſs, when applied to the ſkin, and its leſs abſorbent powers of the moiſture of the ſkin. Wool is therefore, perhaps, a more wholeſome clothing. This power ſeems to depend on the texture of bodies; for ſpongy bodies, ſuch as wool, feathers, &c. touch in ſo few parts, that they abſorb heat from the bodies of animals ſlower than bodies that touch with a greater number of parts. Beſides, wool and fur incloſe a great quantity of air, from their open, porous nature; and air, as well as water, is a bad conductor of heat. 5th. I take this glaſs bulb in my hand, fig. 22, Plate V. and hold it inclined as in the figure: the fluid, rarefied into a ſteam by the heat of my hand, is forced up into the upper bulb; but as ſoon as it diſappears from the lower bulb, and begins to boil in the upper, an intenſe degree of cold ſeizes my hand. Why?—The ſteam flying off from the inner ſurface of the lower bulb, takes along with it a portion of the fire in the ſurrounding bodies (whether in an active or a latent ſtate), and induces on my hand the ſenſation of cold. For the leſs heat that is neceſſary to bring a fluid into the ſtate of vapour, the more intenſe is the cold it produces. Hence, to waſh the hands in æther, would benumb them more than ſnow. Æther applied to an inflammatory head-ache, cools and gives it eaſe; applied to the root of the nerves behind the neck, ſtops a bleeding noſe, &c. If the bulb of a thermometer be dipt in æther, ſpirits of wine, or any fluid that eaſily evaporates, and then expoſed in the air, the quickſilver will ſink a few degrees; for the fluid on the bulb flies off in vapour, and carries with it a portion of the latent fire of the quickſilver. 6th. Hence evaporation cools the earth, the ſea, and even the human body; for the blood, in health, is no hotter in a warm than a cold climate;—as may be proved by putting a thermometer under the arm, in various parts of a long voyage;—for heat cauſes perſpiration, and perſpiration is evaporation, which carries off fire as faſt as it is induced by the hotteſt ſun: and hence the equal temperature of the blood in hot or cold climates.

SECTION VI.

On latent Heat.

1ſt. IF two bodies of the ſame kind, but of different temperatures, be brought into contact, they will ſoon acquire a common temperature, and the quantity of heat in each will be equal: ſhewing that the hotter body has imparted half its ſurplus of heat to the other. The bodies, therefore, to which we apply the thermometer, ſhould be large; ſo that the heat it gives out, or receives, may not ſenſibly affect their temperatures.

2d. The capacity of bodies for retaining fire, or heat, is greateſt in the vapourous ſtate, leſs in the fluid, and leaſt of all in the ſolid ſtate. For all bodies are ſuſceptible of theſe three ſtates. Example.—Water below 32 of the thermometer is ſolid; from 32 to 212 it is fluid (or in a ſtate of fuſion); at 212 it flies off in vapour. Water is kept in its fluid ſtate by the preſſure of the atmoſphere; but that preſſure is overcome by the repulſive force of fire, when its heat amounts to 212; and then, in the gaſous ſtate, the fire is carried off as faſt as it can be adminiſtered to it: *for boiling water, in open veſſels, cannot be made hotter by the greateſt increaſe of heat.* Ex. 2.—Crude iron, at 130° of Wedgewood's ſcale, becomes fluid; and the focus of a large lens will diſperſe it in the character of gas.—So it is with all other bodies.

3d. All bodies abſorb heat, or fire, by a kind of chemical affinity; ſome in greater, and others in leſs abundance; and more in fluids than in ſolids: and yet they ſhall be of the ſame degree of ſenſible heat. If a ſponge and a piece of wood be immerſed in water, the ſponge will ſoon be ſaturated with water; the wood not ſo ſoon, nor will it contain ſo much. We ſhould ſay, then, the ſponge has the greater capacity for imbibing water, though on its ſurface it is not more wet. So it is with different ſubſtances attracting fire; ſome imbibe more, ſome leſs, yet all may be equally warm. If ice be put in water, the water will be brought down to the temperature of the ice, viz. 32; and will continue at that temperature (though the water and ice are placed over a fire), till the ice be diſſolved. What becomes of the ſuperfluous fire? Doubtleſs it is abſorbed by the ice, till it is all melted. So when the fluid is forced into vapour by an intenſe fire, that vapour is never hotter than 212, the boiling point; becauſe the vapour abſorbs the ſuperabundant fire, and carries it into a latent ſtate;—a ſtate that does not affect the thermometer. But ſuppoſe a piece of ice cooled 20° below the freezing point, and a thermometer ſtuck in it, and both expoſed to a hot fire; the thermometer will riſe very uniformly till it comes to the freezing point 32, and there make a full ſtop, till the ice is all liquified, and the fire will ſeem to have loſt its faculty of heating. But after this, the thermometer will riſe regularly, till the water becomes heated to the boiling point, viz. 212, and then it will become ſtationary again.—What is this but two ſtages of the abſorption of fire?

4th. If equal quantities of frozen and fluid water (each at a temperature of 32) be expoſed over a fire, the water will become heated to 162, before the ice is all melted, the ice preſerving the temperature of 32 during the whole time; ſo that the 130° of extraordinary heat produced no other effect on the ice but to render it fluid. For bodies paſſing from a fluid to a ſolid ſtate univerſally emit a quantity of heat; as may be ſeen by applying a thermometer to water in the act of freezing, which will be found ſeveral degrees warmer than the air about it. So, *vice verſa*, when bodies paſs out of the ſolid into the fluid ſtate, they ſteal from the neighbouring bodies a portion of their natural fire, and leave them cold. Snow, or ice, and ſalt, liquifying together, have their capacity for the reception of fire ſo increaſed, that they draw it from all the ſurrounding bodies. Hence veſſels containing cream, water, &c. immerſed in this mixture, will have the cream, water, &c. inſtantly converted into ice. Nitric acid poured on ice (even near the fire), will produce the ſame effect. And ſolutions of Glauber and ammoniacal ſalts, in thin glaſs veſſels within one another, have frozen quickſilver, and made it an hard and ductile metal. But this, Nature has done at Peterſburg and Hudſon's Bay, in a cold 39 degrees below zero, or the cold produced by a mixture of ſalt and ſnow.

5th. Fire (being a conſtituent part of bodies, inherent in, and latent, till called forth by combuſtion, fermentation, change of capacity, &c. into an active ſtate, and capable of affecting the thermometer) is not perceptible to our feeling in its combined or neutralized ſtate. But if the capacity of the body which contains it be altered, it will ſoon become ſenſible. This piece of iron feels cold in my hand ; I lay it on an anvil, and beat it with a hammer, and it becomes hot ; and if the ſtrokes be continued for ſome time, it will become red hot. Why ?—Its capacity to retain fire is altered ; the parts of the iron are forced into a cloſer union, and the latent fire is ſqueezed out, as water out of a ſponge. In reality, the whole of the heat produced by friction or hammering is not altogether afforded by the body itſelf ; becauſe, as the interior fire becomes developed, the external air acts upon the body, calcines or or inflames it: and the air itſelf gives out heat during its fixation. Fermentations, and all changes in bodies, qualify them to receive or expel more or leſs fire, and hence many chemical operations produce ſometimes cold and ſometimes heat. 2d. I force air into the ball of an air-gun; the ball grows warm, yet there is neither friction nor compreſſion induced on the ball:—no, it is the condenſed air within, whoſe latent fire is ſqueezed out, and communicated in an active ſtate to the containing ball. 3d. The Indian rubs two dry ſticks together, and they ignite. The wheels and pinions of ſwift-moving machines take fire. A horſe-ſhoe has its fire beat out by the pavement; and flint and ſteel lend their aid to deſtroy mankind. Fire is contained in a quieſcent ſtate in all theſe: rubbing or friction alters the texture, and condenſes the parts of bodies, ſo as to force out their latent fire, and make it ſenſible. Even water, ſurrounding the borer of a great gun, has been made to boil.

Fire, or caloric, is diſengaged ſometimes in a ſtate of liberty, and ſometimes in a ſtate of combination: it always endeavours to obtain an equilibrium. It is diſperſed among bodies unequally, and according to the degrees of affinity it has to them. Metals are eaſily penetrated by it, and tranſmit it to other bodies with equal facility. Wood and animal ſubſtances receive it to the degree of combuſtion; liquids until they are reduced to vapour. Ice, and all bodies abſorb heat during their liquifaction. Heat (that quality of fire) is ſometimes diſengaged in a ſtate of ſimple mixture, as in the phenomenon of vapours, and of ſublimations, &c. Water and fire unite with ſo weak a combination, that as ſoon as the fire ceaſes to be urged, and the compound is left quiet in air, the fire abandons the vapour, which returns to its fluid ſtate. Evaporations continually carry off with them a portion of fire, and cool the bodies they fly from; hence the blood is cooled by perſpiration, the earth by evaporation, &c. &c. Fire in many caſes contracts a true chemical union with the bodies which it volatilizes, and ſo perfectly, that the heat is not perceptible, being completely neutralized by the body with which it is combined: in this ſtate it is called latent heat, or latent fire. But, can fire, or flame, take place where no latent fire exiſts? If fire can be forced out of bodies that never were near where that principle exiſted; from whence could their tendency to combuſtion ariſe, but from *light*, which all bodies on the earth's ſurface are continually imbibing from the ſun, and from the other concomitant of combuſtion, *the air*, which continually ſurrounds thoſe bodies? For what is combuſtion, but a diſengagement of light from the combuſtible bodies with which it was united—provoked and excited thereto by the heat or ignition of neighbouring combuſtibles already in a ſtate of ignition?

SECTION VII.

On the Affinities of Fire.

1ſt. FIRE, ſo chemically united in bodies, may be decompoſed, or ſeparated from them, by various means; ſuch as more powerful affinities, fermentation, effervеſcence, breathing, &c. for it has its chemical affinities, as well as the more groſs bodies of the chemiſts. Its ſtrong affection for metals will be ſhewn hereafter; but its extrication from the air we breathe, and the food we eat, more immediately aſſimulates with our preſent ſubject. We are inſtructed that the air probably conſiſts of three ingredients in its unadulterated ſtate, viz. oxygen gas, or vital air (conſtituting about one third of its maſs); azotic air; and fire. Air taken into the lungs, undergoes a decompoſition; much of the vital part uniting itſelf with the blood: the azotic part is thrown out, with a quantity of fixt air (or carbonic gas); and the latent fire is let looſe in the lungs, and carried by the blood, in an active ſtate, through every part of the body, producing animal heat. The decompoſition of our food in the ſtomach alſo extricates a quantity of latent fire, which, joining *that* developed in the lungs, gives that ſteady warmth to living animals, unknown to the inanimate parts of nature: and hence animals without lungs, are of the ſame temperature as the mediums in which they live; as fiſh, frogs, &c.

2d. That bodies are not diſpoſed to draw fire into a latent ſtate, until they arrive at their melting point; nor fluids to part with it, until cooled to a certain degree; will be proved hereafter by many experiments; and may at preſent be evinced by the ſlowneſs with which ice and ſnow melt when a thaw comes on, and the heat of the air is far above the freezing point: this abundant heat is abſorbed by the melting ice, and prevents the country from being deluged by ſo rapid a thaw as the warm air would ſeem to indicate. It is owing to this, that ice is preſerved in ice-houſes, and ſnow on the mountains, even in ſummer heat. Water, at reſt, may be cooled ſeveral degrees below the freezing point, before it will congeal, as may be ſeen by a thermometer immerſed in it; but if touched with the end of a wire, a bit of ice, or if the veſſel be agitated, in an inſtant it becomes ſolid. If the thermometer be ſtill in the water, it will inſtantly riſe up to the freezing point; and prove that a quantity of latent fire has emerged from the water.

Theſe few examples will ſuggeſt more; and ſhew by what ſimple cauſes the greateſt and moſt wonderful effects of nature are produced!—They lead us by degrees to the firſt cauſe, the Author of ſuch admirable uniformity, amid ſuch infinite variety!

END OF THE FIRST LECTURE.

LECTURE II.

Of the Particles of Matter, their Minuteneſs, Hardneſs, Extenſion, Diviſibility, Inertia, and Coheſion; and on Magnetiſm.

SECTION I.

PHILOSOPHY, like the ſciences, has its firſt principles: matter and its properties are the objects of its reſearch. By matter we mean every thing ſolid or fluid in nature, and we conceive this matter to be made up of particles ſo infinitely ſmall, as not *only* to eſcape the ſcrutiny of the higheſt magnifying powers in glaſſes, but that even imagination itſelf is incapable of forming any idea of the ſize of an original particle of matter! When we have reduced matter to the moſt impalpable powder, we are far, very far, from the atoms which compoſe that powder. I diſſolve a ſingle grain of copper in an ounce of diluted nitrous acid: this ſolution will cover 1000 ſquare inches of bright iron completely with a ſkin of copper, or impart a green colour to a gallon of water. One pound of gold is capable of covering a wire that will circumſcribe the globe! Muſk, aſſa-fœtida, camphor, and many other eſſences, will exhale for weeks, and throw off their particles to the diſtance of ſeveral yards, without loſing any ſenſible weight! Nay, Lewenhoeck diſcovered more living animalculæ in the milt of one ſingle cod-fiſh, than there are men, women, and children, on the face of the earth! We deal not in thoſe ſubtilties, where the whole matter of the univerſe is ſuppoſed capable of being compreſſed into the ſize of a walnut; or where an inch of common matter may be extended to the ſize of a world; they ſerve only to perplex enquiry, and by no means to promote the progreſs of truth: they will be ſtudiouſly avoided in the following lectures. For while the myſteries of religion engroſſed and perplexed the ſtudies of our forefathers, the metaphyſical ſpirit thence engendered infuſed itſelf into philoſophy; and hence the ſolemn definitions and unintelligible jargon reſpecting extention, diviſibility, impenetrability, &c. It is certainly ſelf-evident, that every kind of body muſt have extenſion in length, breadth, and thickneſs; that one particle cannot be thruſt through another, nor one body occupy the place of another, while that other is in it. We have, indeed, many reaſons to believe the original particles of all matter to be impenetrably hard; not only from experiment, but in order that nature might be immortal and incapable of wearing out. Electric matter (the ſubtileſt matter we know), in paſſing through the human conſtitution, gives a real mechanic ſtroke to the ends of all the bones it meets in its way. In its exploſions, it cauſes a vacuum in the air, the parts of which ruſhing together, after the exploſion, produce the reverberated crack we call thunder. Muſt not the air and electricity be, therefore, made of hard particles? We tie a ſoaked bladder over one end of an open cylinder, *a*, fig. 1, Plate VI. and dry it ſlowly by the fire; if then it be placed upon the plate of an air-pump, and the air under the bladder be exhauſted, the column of air *b* will, by its weight, burſt the bladder, and, falling on the pump-plate, make a report equal to a piſtol. Could this be the caſe, if the particles of air were not hard? Water alſo, like air, yields to the lighteſt impreſſion; its particles ſlide over each other with the utmoſt eaſe; yet water falling through a vacuum, on metal, or any hard body, will ſtrike it with as loud a click as if one piece of iron fell on another. The water-hammer, as it is called, proves this. The ſpace *a*, fig. 2, Plate VI. is a vacuum, *b* is water. Now if the glaſs be inverted, the water will fall into the bulb *a*; if it be then ſuddenly turned into its firſt poſition, it will fall on the bottom *c* with a loud clic. This effect does not take place when the veſſel has air in it; for air divides the water that falls through it, and prevents its ſtriking the veſſel in a body, as it does in the above vacuum. Muſt not the particles of water, therefore, be hard?

SECTION II.

BUT one of the moſt wonderful affections of matter, is its property of attracting and being attracted. Every particle of matter has a tendency to unite with other particles, if not prevented by the repulſive power of fire (or caloric), or a ſtronger affinity, as will be proved hereafter. The cavillers at the Newtonian doctrine quarrel with the word attraction; and much waſte paper has belumbered the world, in diſputing whether it is a cauſe or an effect. It is natural to ſuppoſe that one body cannot act upon another but by means of ſome interpoſing medium; but we have never been able to diſcover what this medium is. We know that the particles of matter are held together by ſome ſort of influence they have upon each other; and why not call it attraction? What is it to us, whether it is inherent in matter, or a quality imparted to it by the Author of nature? Its effects and operations, addreſſed to our common ſenſes, are the objects of philoſophical enquiry. Before we proceed further, it will be neceſſary to note a few axioms reſpecting attraction and repulſion.

All bodies, whether ſolid or fluid, are compounded of attracting and repelling matter.

Bodies, in which the attracting and repelling matter are equal, will balance, and neither attract nor repel (but it is when they are at that critical diſtance where their attractive and repellent powers balance each other), as *a*, &c. fig. 23, Plate V.; where the repellent matter is repreſented by the dotted lines.

Bodies that contain more attracting than repelling matter, will attract with a force proportionate to the exceſs of attracting matter.

Thoſe bodies whoſe repellent fire is not confined to their interior parts, but emanates round them in the form of atmoſpheres *, while they are at a diſtance will neither attract nor repel, as *a*, *a*, fig. 23, Plate V.; yet when they are forced nearer together, ſo that their atmoſpheres begin to mix, unite, and coincide, they will then begin to attract. On their approach, the repellent particles that compoſe their atmoſpheres will be forced backwards behind the bodies, as *d* and *g*; ſo that when the bodies come to a certain

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* It is to be obſerved, that the diſtance where the attractive and repellent powers balance each other, is much regulated by the temperature of the body: if it be warm, the repellent power may ſtop or balance the attractive power even without, or at a diſtance from, the body; but if cold, it may be within the body, and no appearance of repulſion may be detectable. So that theſe powers ſeem to have too laconic a definition, when it is ſaid, that "where the ſphere of attraction ends, repulſion begins."

diſtance from each other, there will not be ſo many repellent particles between them ſufficient to balance their force of attraction; on which account they will run together, and their atmoſpheres will ſo mix and unite, as to make up but one atmoſphere to both.

Upon how noble a ſcale is this exemplified in the ſun; who *repels* by his *fire*, and *attracts* by his *body*; and ſeems as if he gave orders to every part of his ſyſtem to be obedient to that law!

When bodies are preſſed together, the repulſion on the ſurfaces reacts as a ſpring. When bodies are ſtretched, as a muſical ſtring, if diſtended as far as where the repulſion begins to take place, their force of attraction will be then overcome, and the ſtring breaks. So in bending ſprings, one ſide is compreſſed, the other expanded; and therefore both effects take place. Therefore, when attraction prevails in bodies, they become ſolid; when fire prevails, they become gas: hence fluidity ſeems a medium between the two Let us try then, in the firſt place, to prove that ſuch attraction exiſts. Preſs two glaſs plates together, whoſe ſurfaces are even, and you will find how difficult it will be to pull them perpendicularly aſunder. I ſcrape the flat bottoms of two ſmall leaden cones pretty even, then preſs them together with a ſmall twiſt (to unite the particles better, not to link them), and find 100 pounds will ſcarcely ſeparate them. In ſhort, the particles that do really touch in the oppoſite ſurfaces, adhere as ſtrongly as the particles that compoſe either cone; for had every particle in one ſurface come in contact with the particles of the other ſurface, then would the two cones have become one maſs, as much as if they had been caſt in that form, when in a ſtate of fuſion. If the two flat ſtones with which we grind colours, be ſuffered to reſt for a minute, they become almoſt immoveable; to continue their motion, requires little ſtrength. This attraction therefore is gradual, when particles are deranged, or lie inconveniently by one another. Two iron planes, poliſhed mathematically even, adhere ſo ſtrongly, that twenty-four ſtrong men have tried to pull them aſunder, without effect. Two marble planes ground perfectly flat, have a little oil ſpread over them, to fill up ſuch interſtices as are uſual in ſtones; when preſſed together, a ſteel-yard is applied to determine what weight will pull them aſunder. The planes are then preſſed together as before, and ſuſpended through a collar of leathers in the receiver of an air-pump, and the air exhauſted. The ſteel-yard then applied to the wire which comes through the collar of leathers, ſeparates the planes in vacuo with the ſame weights as in the open air (allowing a little for the friction of the wire and leathers). This ſhews that the attraction is totally independent of the weight and preſſure of the atmoſphere. Why do drops of rain, on the leaves of plants, aſſume a globular form? or why are they globes in their deſcent from the clouds? Why does water become convex, when its ſurface is raiſed above the edge of the containing veſſel; or concave, when the edge of the veſſel is above the water? Or why do two globules of quickſilver run together, and form one globe?—Balance a piece of board on the end of a ſcale-beam; then let it lie flat on water, and ſix times its weight will not ſeparate it from the water. Theſe, and ten thouſand ſimilar effects, might be brought to prove that it is an attraction among the parts that produces all theſe effects. Place pieces of cork on ſtill water, about an inch diſtant, and they will run together with an accelerated motion; or, if near enough, creep to the ſide of the veſſel. Nay, the largeſt ſhips ſailing near one another, in the ſame direction, have been known to run foul of each other, in ſpite of the rudder. The above experiment I know has been objected to, becauſe if a piece of cork be placed near the edge of the veſſel, when it is a little more than brim full, it will recede from the ſide: but this, I apprehend, does not invalidate the doctrine; for certainly the water which riſes up the ſides of ſwimming bodies, ſpecifically aſſiſts their union: for very light and dry bodies, which lie on the ſurface of water without becoming wet, have not ſo powerful an attraction; but at a proper diſtance (i. e. where the attractive and repellent powers meet) will be repelled by a wet finger, or a round knob of metal, or ivory, particularly if a little warmed.—Example: If a ſmall pith ball be thrown on a bowl of water, and a round knob be half immerſed near it, the ſmall ball may be driven round the bowl, though the knob never touches it. The ſame attraction which makes the water riſe globularly above the veſſel, will draw a light cork from the ſide towards the centre; as the power or energy of this attraction is in proportion to the quantity of matter, the buoyancy of water, the ſolidity and diſtance of the attracting bodies.

By the ſame attractive power are formed ſtones, metals, woods, ſalts, and every thing that may be denominated body. The effects of ſolders, glue, cements, &c. are all from the ſame cauſe. So jewels, hard ſtones, ſtalactites, petrifications, porcelain, pottery, bricks, flags, glaſs, cements, artificial ſtones, and plaſtic earthy compoſitions, which preſerve their figure in drying, all are children of that great agent, Attraction.

The particles of air and water alſo mutually attract each other, as may be proved by expoſing concentrated acids, or fixt vegetable alkali, to the air, which will ſoon attract and detach a ſufficient quantity of water from the air, and become fluid. It is alſo evident in the drying of wet clothes in air; in the quick diſſipation of moiſture breathed on glaſs, poliſhed metals, &c.; in hygrometers; in water depoſited by cooled atmoſpheric air on the outſide of decanters filled with cold water; by air cooled after paſſing through red-hot tubes; and by water precipitated from air, while rarefying on the air-pump.

As this power is much greater in ſome bodies than in others, there ariſes an infinite variety in the ſtrength, the weight, the texture, &c. of metals, ſtones, &c.; for we have powerful reaſons to believe that the original particles of all matter are of the ſame weight; and that it is the attraction of coheſion that makes the great difference in their ſpecific weight. To minds not uſed to philoſophical inveſtigation, it muſt appear a bold aſſertion to ſay, that the particles of gold are not one whit heavier than the particles of cork: but what ſay experiment and obſervation to this? Suſpend two or three guineas, with a feather on each, on the ſhelves *a*, fig. 3, Plate VI.; the tall glaſs being then exhauſted of air, the guineas and feathers may be dropt by means of the trigger *b*, operating through a collar of leathers, and will ſtrike the bottom at the ſame inſtant, if the glaſs *c* was even five or ſix feet high. Why then do not heavy and light bodies fall equally ſwift through the air or water? Becauſe theſe fluids form a great reſiſtance to bodies that paſs ſwiftly through them; and their reſiſtance being in proportion to the ſwiftneſs and ſurface of the bodies; if the feather is as large as the guinea, they will be equally reſiſted in their paſſage through the air; but then as the guinea contains ſo much matter more than the feather, there is a balance in its favour, by which it will overcome the reſiſting medium, and fall faſter; but where that reſiſtance is taken away (as in the exhauſted receiver), their particles being equally heavy, they fall exactly in the ſame time. Otherwiſe, how ſhould gold be ſuſpended in a liquor, little heavier than water? for gold can be diſſolved in aqua regia, like ſugar in water. If the particles of gold, ſo ſeparated, were heavier than the menſtruum in which they are ſuſpended, they would ſurely ſink to the bottom. Beſides, every one knows that leaf gold will, for a time, float in air.

Water is, bulk for bulk, 850 times as heavy as air; yet water will riſe in air, becauſe its particles, ſeparately conſidered, are no heavier than the particles of air; the two elements mutually diſſolving, and incorporating with each other. Iron becomes homogeneous with diluted ſulphuric or vitriolic acid; and its oxyd, or calx, will remain incorporated with it. Copper is diſſolved alſo by diluted nitric acid. So is glaſs, or ſilicious earth, with ſparry acid. Are not iron, copper, and glaſs, heavier in their natural ſtate, than the menſtruums in which they are diſſolved? Certainly. But ſome will ſay theſe are chemical attractions; ſo they are: but let thoſe who are fond of multiplying cauſes, demonſtrate to me, that chemical attractions are not modifications of the attraction of coheſion. Of this hereafter.

SECTION III.

On Capillary Attraction.

CAPILLARY attraction is only another mode in the action of the attraction of coheſion. It is called capillary, from the tubes, which draw water above its level, being ſmall as hairs. Theſe tubes attract in a reciprocal proportion to the bore or diameter: the ſmalleſt attract moſt, having their oppoſite ſides contiguous; they give great aſſiſtance to each other, and draw the fluid two or three inches above its level. But wider tubes, having their oppoſite ſides too diſtant, draw it not above a few tenths of an inch. For the ſphere of this attraction in general reaches but to a very ſmall diſtance from the ſurface of the bodies.

If three or more capillary tubes be fixed to a wire that paſſes through a collar of leathers into ſuch a receiver as *d*, fig. 17, Plate V.; when the air is extracted by the air-pump from the receiver, and the tubes are then juſt dipt in a veſſel of water, the water will riſe to the ſame height in them as in the open air, ſhewing that the preſſure of the atmoſphere has nothing to do with the riſe of fluids in capillary tubes.

Two wet glaſs planes, fig. 4. Plate VI.; ſeparated on one ſide by a ſhilling, and immerſed in water, when lifted out, will exhibit a curve, called the hyperbola; that ſhews the ratio of this attraction to be as the ſquares of the increments with which the planes open, viz. as 1, 2, 3, 4, &c.; as 1, 4, 9, 16, &c. And here it may be obſerved, that the laws of nature ſeem generally to be regulated by the ſquares of numbers; as if that had been a principle in the Almighty Mind, when he created and gave laws to the univerſe.

It is inconceiveable the multitude and variety of operations in nature, that capillary attraction explains. All vegetables are but bundles of capillary tubes: and whether we conſider earth, water, ſalt, and oil, as the food of plants—or, with Kirwan, that coal is eſſential to that food—or with Ingenhouz, that it is vital air decompoſed into fixt air and azote; ſtill that food muſt be formed by water into an emulſion, capable of being acted upon by capillary attraction: and as all roots are but aſſemblages of theſe tubes, there can be little doubt but their attraction ſupplies the plant with its firſt food; though other cauſes muſt aſſiſt in carrying it to the tops of the talleſt trees, ſuch as dilatation and contraction, by the ſucceſſive heat and cold of day and night, the muſcular action of vaſcular rings round the tubes irritated to contraction by the ſtimulant ſap, &c. The interior bark conducts the nouriſhment ſupplied by the earth. Leaves on one ſide draw nutrition alſo from the air, and perſpire on the other: light probably does the reſt.

This principle is not leſs active in the animal than the vegetable world. The ſtomach may be called the animal root; and by its action, and the gaſtric ſolvent in it, food is alſo formed into an emulſion, and acted upon by abſorbent or capillary tubes, under the names of lymphatics, lacteals, &c. drawing the finer part in a milky ſtate to the heart, where, uniting with the venal blood, it is taken up with it to the lungs; and from the vital part of the air it meets with in them, derives its red colour. All the ſecretions in the inteſtines, &c. are carried on by the ſame law. Even the ſkin itſelf may be ſaid to be little more than capillary pores, through which emulſions may be rubbed, forming the topical applications of ſurgery. In civilized life, theſe pores ſerve, in general, to throw off redundancy, and help digeſtion. In general, we eat and drink more than nature requires; the ordinary evacuations are not enough to carry all off; much perſpires through the ſkin: and it is well known, we in general loſe more weight by what is called inſenſible perſpiration, than by any other evacuation whatſoever. Hence ariſes the neceſſity of a perpetual change of our linen and clothes; for what are they but bundles of capillary tubes, abſorbing this matter from the ſkin? Dip you handkerchief in water, and the water creeps up it, above its ordinary level. Touch its ſurface with a ſponge, the water riſes in it above its level. Raiſe a heap of ſand in a flat veſſel and pour water round the ſand, the water will riſe to the top of the ſand above the water. Glue is attracted into the pores of wood, and becoming hard, forms the bond of union between two pieces of wood. All theſe inſtances, and thouſands more, are the effects of capillary attraction.

Nay, a living body is capable of deriving nutrition even through the pores of the ſkin. The lone ſavage lays him down naked on his parent earth, when fatigued with long marches and hunger, and finds that hunger abated by the contact his body has with the ground. Nor ſhould we be incredulous when we hear of a late empiric, who could live for weeks together, by burying himſelf to the neck in earth: ſince every ſailor knows, that in a ſcarcity of freſh water, he dips his jacket in the ſea, and, putting it to his naked ſkin, finds his thirſt allayed by that expedient. The reſources of nature, to preſerve animal life, are wonderful in the extreme!

SECTION IV.

On the Polarity of Matter.

THE diverſity occaſioned by the unequal attraction in metals, ſtones, &c. is much increaſed by what may be called the *polarity of matter*; or that mode of arrangement which different ſubſtances take in paſſing out of a fluid into a ſolid ſtate. For all bodies are capable of three ſtates, viz. ſolidity, fluidity, and a *gaſſous* ſtate. Water, at 32 degrees of Fahrenheit's thermometer, is cold enough to become ſolid, in the character of ice; a little heat, and the preſſure of the atmoſphere, makes and keeps it fluid, and we then call it water; but if that heat be increaſed to 212° of the ſame thermometer, it will overcome the preſſure of the atmoſphere, and fly off as gas, in the character of ſteam. So iron will preſerve its ſolid form, till it be heated to 130 (Wedgewood's ſcale). It will then become fluid, and the heat increaſed will diſperſe it as gas. Even diamonds, the hardeſt ſubſtance we know, are capable of being diſperſed by a common culinary fire; though gold, in its pure ſtate, bids defiance to the utmoſt power of heat. It has been kept boiling in the focus of the largeſt lens ever made, for eleven hours, without loſing a grain of its weight. Though when its particles are ſeparated by being diſſolved in aqua regia, it eaſily aſſumes the gaſſous ſtate, with a ſmall degree of heat. This, therefore, is not conſidered as any exception to the axiom, that all bodies are capable, in certain circumſtances, of the three ſtates of *ſolidity*, *fluidity*, and *gas*. But the polarity of bodies ariſes from the manner in which the particles approach, and lay by the ſide of one another, when the fire that kept them ſeparate, ſubſides, and the attraction of coheſion draws them together into a ſolid: for if fluid iron be diſturbed in cooling, it will not have all the properties of iron, it will become fluid; but it will want the natural texture of iron, its colour, and ſome of its ſtrength. If water be ſtirred with a ſtick, while freezing, it will not be ice, though it will become ſolid; for water is a ſalt in a ſtate of fluidity, and cryſtallizes in a certain degree of cold; and its polarity, or mode of arrangement even in its ſolid form, may be ſeen on the frozen moiſture upon a window. The forms aſſumed by different ſalts, ariſe from the ſame cauſe. Even metallic arrangement may be conſidered as a ſpecies of cryſtallization. Hence metals differ from metals; ſtones from ſtones; wood from wood; &c. and add to the immenſe variety occaſioned by the different degrees and force of coheſive attraction. Light angular bodies ſwimming near one another on water, will run together, and unite their ſides, in the moſt convenient manner, to make one body; illuſtrative of the manner in which the particles of matter arrange themſelves in the act of cryſtallization, as in fig. 5, Plate VI. where the ſides of ſalts, and other matters, accommodate themſelves to one another, and form a ſolid.

May not trees and all other vegetables be conſidered as a kind of terreſtrial cryſtallizations; where light and air are the nurſing pabula? May they not riſe out of the earth, as ſalts ſhoot? Water in a certain degree of cold, and in a very thin ſheet, ramifies like a beautiful tree. Silver detached from its union with nitrous acid, by copper, ſhoots into a beautiful wood, called the arbor dianæ: and all metals in cooling from a fluid into a ſolid ſtate, aſſume tree-like figures. Even animals are but vegetables, attached to their mother by the umbilical cord. Why do the cryſtals of ſhooting ſal-ammoniac ſtop whenever they come near other cryſtals? perhaps for the ſame reaſon that the branches of trees ſtop in their growth, or turn away, when they meet a wall, the earth, water, or a neighbouring tree. Do not all vegetables ſhoot towards the light? Cloſe-wooded trees have no leaves but on their outſides, and towards the light. Bloſſoms are almoſt without, and never within, cloſe-wooded trees; ſo are their fruit. Trees planted cloſe, deſtroy the underwood, and have no leaves or bloſſoms but on their tops, being the only part that has good acceſs to light: hence cloſe-planted trees ſhoot up towards the ſun, become very tall, very ſmall, and very ſtraight. The ſkeleton of a leaf is very ſimilar to the arrangements in cryſtallization.

Cover a living plant with a box that has a hole in it: the plant will lean towards the hole, and in time find its way through it. Hence vines planted within a houſe, and having their branches without, thrive, and produce better than when the whole tree is within or without the houſe, &c. The dry-rot (as it is called) in houſes, is a vegetable that preys on moiſt wood, both at its root, and by its ſmall fibres, which in the progreſs of the plant ſtrikes into the wood; ſo the plant may be conſidered but as one continued root, macerating the boards and beams to which it adheres, deſtroying their texture and coheſion ſo as to make them crumble into duſt when dry. This inſidious plant, though working ruin and devaſtation in the dark, is ſtill aiming in its progreſs towards the light: its ramifications are imperfect, as well as its colour; and it is killed by letting in a current of air to dry up the moiſture it loves. How like is this to the attempts which nature makes to arborize copper, tin, iron, &c. in the dark receſſes of a mine! or to the woods of coralline matter that arborize millions of acres in the bottom of the ſea! Though this laſt may be ſomething-like proved to be the work of melipodes or marine inſects, yet, if that be true, it aſtoniſhes the mind with the uniformity of nature! Are not the weeds of the ſea like the arboric appearances we find in the hardeſt pebbles? Do not vegetables thrive and increaſe more when ſupported by a wall, or eſpalier, than when left to the ſupport of their own ſtem? and do not both minerals and ſalts cryſtallize better when they have a ſmooth glaſs, wood, metal, or ſtone ſurface, to creep up, and adhere to? Many more conformities might be found out; but theſe are enough to prove the analogy.

SECTION V.

On Magnetic Attraction.

MAGNETIC attraction is confined to iron, ſteel, and the natural magnet *, which natural magnet is a ponderous iron-ſtone, of a blackiſh colour. This wonderful ſtone is ſuppoſed to derive its power of attracting and repelling, from the poſition in which it laid in the earth: for, from the quantity of ferruginous, or irony matter, contained in the earth, as well as many other phænomena, there are ſtrong reaſons to believe the globe itſelf to be one great magnet. Steel, ſtruck by lightning, or a ſtrong ſhock of electricity, acquires polarity or magnetiſm: hence it is natural to imagine, there is a relationſhip between electricity and magnetiſm.

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* Cobalt, nickel, and manganeſe, reſemble iron in many particulars, and are therefore all a little affected by magnetic attraction.

If a bar of ſteel be balanced on a point, one part of the ſtone will attract it, and an oppoſite part of the ſtone will repel it. May we not apprehend this to be occaſioned by a ſubtil effluvium, inherent in the magnet? and that it may have its poſitive end and negative end, like the two rubbers on the oppoſite ſides of an excited electrical cylinder—one in a ſtate of condenſation, the other in a ſtate of rarefaction? For if two bodies approach each other, one poſſeſſed of condenſed or poſitive electricity, and the other of rarefied (or what is called negative) electricity, they fly together, and unite with avidity: but if the two bodies were poſſeſſed alike of either condenſed or rarefied electricity, they univerſally repel each other. This is ſtill but Nature ſtriving for that equilibrium conſpicuous in all the inequalities of her works; the poſitive ſtrives to meet the negative, and the negative ſtrives to meet the poſitive, that equality may be produced. So it is in magnetiſm.

1ſt. If iron filings be ſhaken through a gauze ſieve, upon a paper that covers a bar-magnet, the filings will become magnets, and be arranged by the incumbent magnet in the beautiful curves ſeen in fig. 6, Plate VI. Upon the two ends of the magnet at *a a*, the filings ſtand perpendicular, and ſeem buttreſſes of arches that would ſtand over the magnet; on the ſides of the magnet they ſlope, or incline, and ſeem buttreſſes of inclining arches: ſo that if filings could be ſuſtained all round the magnet, above and below, they would probably aſſume an egg-like figure. Is not this appearance favourable to the idea of a condenſed and rarefied magnetiſm; where the abundance ſolicits want, and where want ſolicits the abundance? and where in the middle of the magnet the union is formed, and an evident endeavour made at both ends?

Electricity, in its efforts to produce an equilibre, by either attraction or repulſion, always acts in curves: ſo does magnetiſm. Place two bar-magnets, like fig. 6, Plate VII. about two inches diſtant from each other in a line, and with a condenſed to a rarefied end; place paper over them, and ſift iron filings on the paper, as in the laſt experiment, and the filings will be arranged in curves like *c c*. The ſame arrangement may be ſeen at *S*, *N*, in fig. 8, Plate VII.

2d. If two pieces of ſpring-tempered ſteel, formed like horſe-ſhoes, as *A* and *B*, fig. 7, Plate VI. with the ends *a*, *b*, and *c*, *d*, be put together, and two bar-magnets (ſeparated as *e* and *g*, and their marked ends in contrary direction) be rubbed round the horſe-ſhoe bars, with the bar *e* always foremoſt, magnetic virtue will be excited in the two bars, and they will adhere together, as if by a hinge: if then the horſe-ſhoes be laid on each other, and the four attracting ends be placed together on a piece of iron, they will not attract it, but ſeem as if they had loſt their attractive power. Now if a fluid be the cauſe of magnetiſm, it is natural to ſuppoſe this fluid muſt flow through the pores of the horſe-ſhoe bars in the ſame direction in which they received it, viz. from *b* to *a*, and from *c* to *d*; and conſequently that *c* muſt be a delivering pole, and *a* a receiving pole. In like manner, that *e* muſt be a delivering pole, and *d* a receiving pole: and this will be found true, if the pole *a* be held about an inch from one end of a ſuſpended compaſs-needle, it will repel it; but if *b* be addreſſed to the ſame end of the needle, it will attract it. In like manner, *c* will repel, and *d* will attract. Now when one of the horſe-ſhoes is laid on the other, with the poles *a b* together, and the poles *c d* together, it is evident an attracting and a repelling pole are put together, which muſt form a counteraction, and make them ſeem as if they had loſt their virtue, when placed on a piece of iron; for one may be ſaid to be pulling, while the other is thruſting. But if the receiving poles, *a* and *d*, be put together, and the delivering poles, *b* and *c*, be joined, when the bars are laid one on the other; then if the four poles are placed upon a piece of iron, they will immediately take it up. It is in this manner, and on this principle, the ſtrong horſe-ſhoe magnets are formed, where ſix or eight ſuch bars are rivetted together, and will lift upwards of an hundred weight. But in order to make a regular road for this ſubtil effluvium, it is neceſſary a piece of iron ſhould always be in contact with the attracting and repelling poles, by way of a magnetic conductor, and prevent that tendency towards condenſation and rarefaction in the two ends, which is uſually the caſe where a conductor does not unite them.

3d. Two ſemicircular magnets, *A* and *B*, fig. 8, Plate VII. having their poles dipt in iron filings, the filings will ſtick radiantly to the poles in every direction. If the pole *a* be brought within half an inch of the pole *b*, and the pole *c* at the ſame diſtance from *d*, the filings will leave their radiant direction, and catch hold of the filings of the oppoſite poles: for *a* and *c* being delivering poles, and *b* and *d* receiving poles, a magnetic circuit is formed, and the filings become conductors. But if the pole *a* be addreſſed to *c*, and the pole *b* to *d*, the filings will not unite, but repel thoſe oppoſite to them, as fig. 9, Plate VII. In one caſe, the magnetic effluvium has a regular circular road; in the other, the fluid of one magnet meeting the fluid of the other, a repellency takes place. Are not theſe experiments ſtrongly indicative of an electrio-magnetic fluid?

4th. The efforts which this wonderful principle will make, to *accompliſh* itſelf an equilibrium by means of iron or ſteel conductors, are beautifully exhibited, by ſuſpending three or four ſmall iron balls by one of the poles of the magnet, fig. 10, Plate VII. If then a piece of iron be made to touch the other pole, and ſuddenly to communicate with that by which the balls hang, the balls inſtantly fall from the magnet. Theſe balls may be ſuſpended by either of the poles, for the rarefied end will make an effort to unite with the condenſed end to form the magnetic circuit as effectually as the contrary; ſo ſoon, therefore, as the bar *q* has completed the circuit, the balls are forſaken, and drop off.

5th. When three of the balls are ſuſpended from each pole of the above magnet (for except the magnet be very ſtrong, it will not ſuſtain more perpendicularly), if two others are ſo added that they all touch each other, they will adhere circularly to the two poles, and form the image, fig. 11, Plate VII. Can this be for any other reaſon, than becauſe the balls and the magnet make one complete magnetical circuit?

6th. If ſeveral ſteel bars be placed in a line, touching each other, and the north (or *marked*) end of an horſe-ſhoe magnet be ſlid foremoſt over them ſeveral times, in the ſame direction, the bars will adhere to one another, and be all lifted by one of the bars. If then they are placed as at firſt, and the *unmarked* end of the magnet be ſlid foremoſt over them, as before, the attraction of the bars will be deſtroyed, and they will not betray the leaſt ſigns of magnetiſm. Muſt not this ariſe from confuſing the magnetic circuit; tending to turn that into a receiving, which before was a delivering pole?

7th. If one end of a poker (or any bar of iron that has for any length of time ſtood in a perpendicular poſition) be held near one end of a compaſs-needle, it will attract it; but if the poker be moved ſlowly, in its firſt poſition, till its other end comes near the needle, the needle will be repelled. Is not the poker a magnet?—Beyond a doubt. But how came it ſo?—By ſtanding in the way of the earth's magnetic effluvium. For if a new forged needle be balanced on a point, and then have magnetiſm given to it, by either a natural or artificial magnet, and be ſuſpended again on the point, it will be found to have loſt its balance, and will point ſo as to form an angle with the horizon of about ſeventy-three degrees; ſee fig. 12. Plate VII. This is called the dip of the needle; and is moſt rationally accounted for, by its effluvium falling into, and becoming influenced by, the ſtream of the earth's magnetic effluvium. Iron railing, upright bars in windows, tongs, pokers, &c. all become magnetic by their upright poſition; or rather by that poſition being ſo nearly parallel with the dip of the needle.

8th. If a ſmall thin piece of ſteel be ſuſpended by its centre of gravity, between two fine points, and placed on one end of a bar-magnet, it will ſtand perpendicular to the bar: if it be then ſlid towards the other end of the bar, it will begin to incline towards a level: at the middle of the bar it will hang horizontally, and then incline and ſtand with its other end perpendicular to the bar.

Is not this a proof, that the globe of the earth is one great magnet? and that a ſimilar effluvium flows through it, as through thoſe magnets thus deſcribed, and thus detached from it?

9th. Take the poker *a*, fig. 13, Plate VII. hold its knob near one end of the compaſs-needle, and it will attract it: keep the knob in the ſame ſituation, but turn the poker upon it (as on a centre) into a contrary poſition, as *b*, and inſtantly the knob will repel that end of the needle it attracted before, and attract the other end of the needle; ſhewing, that the poles of the poker were changed by the change of its poſition. This experiment ſucceeds beſt, when the poker points towards the earth's magnetic pole, at an angle of 73° with the horizon; for then it is parallel with the earth's effluvium, and partakes, as it were, of it; ſo that, when the point of the poker is upwards, it receives the effluvium, and becomes what is called a ſouth pole; and its other end is a north pole, and attracts the ſouth pole of the needle. But when it is inverted, and the knob points upwards, that end of the poker becomes the receiving, or ſouth pole, and conſequently repels the ſouth pole of the needle; conformably to the idea, that a ſubtil *ſomething* flows through the earth, the ſea, and the air, that has a peculiar affinity to iron, ſteel, and the natural magnet; making theſe ſubſtances into magnets, by only being in its way.

As iron, or ferruginous matter, is more particularly diffuſed through the body of the earth than any other metal, and that in a regular form (for iron-ore is not attracted by the magnet), this effluvium can never be in want of its conducting matter: but why that power ſhould aſſume thoſe ſerpentine and other forms we ſee in the lines repreſenting the needle's variation, is yet unknown. Some ſuppoſe that the diurnal rotation of the globe, or ſubterranean fires, may cauſe this ſingular arrangement in heavy materials, and alſo occaſion their removal weſtward. But this is merely conjecture; no obſervations yet made, give it the leaſt countenance.

10th. That this virtue has a progreſſive tendency, is evident; for if a ſteel wire (rendered magnetic) be twiſted into a ſpiral ſpring, the virtue is ſtrangely confuſed. It will attract in ſome places, in others repel. Nay, in ſome places, one ſide of the wire will attract, and the other ſide repel; ſhewing the diſpoſition of the fluid to flow forward, and form a circuit.

11th. A bar of iron made red-hot, and quenched in water, or cooled in air, ſtanding in the poſition of the dipping-needle, will acquire magnetiſm. Does not the earth's magnetic fluid, flowing through the ductile metal, adapt or arrange its pores, both for the reception and retention of magnetiſm?

12th. For the ſame reaſon, if a bar of iron be fixed in the direction of the dipping-needle, and rubbed all one way, with the end of a ſteel bar, or even a pair of tongs, the iron will become a magnet.

13th. A ſmart ſtroke of a hammer on the end of a bar, ſtanding in the direction of the dipping-needle, will give it magnetiſm; and the poles may be changed by ſtriking the other end.

14. If a bar, in the above poſition, receive a ſmart electrical ſhock, it becomes inſtantly a magnet; the end towards the earth (or rather towards the north magnetic pole) becoming a north, or delivering pole, and the other a ſouth, or receiving pole; and it is well known, that a ſtroke of lightning has often changed the poles of a mariner's compaſs-needle.

15. That iron receives a magnetic virtue by ſtanding in the di-

rection of the earth's magnetic effluvium, is not more remarkable than its acquiſition of magnetiſm by being held lengthwiſe near the poles of an horſe-ſhoe magnet; when, by trying it with iron filings, it will be found to hold them at each end, as if it had been regularly impregnated. Nay, if ſo heavy a piece of iron be held to the poles of a magnet that it cannot ſuſtain it, if another piece be held a little below it, the magnet will ſuſtain it. What wonderful efforts will not this power make to acquire a circuit and regain an equilibrium!

16th. Theſe arrangements and polarities are beautifully exemplified, by filling a glaſs tube with iron filings; if the tube be touched by a magnet (as if it were an iron bar), the glaſs will appear to have acquired magnetiſm, and will attract filings. But ſhake or diſturb the filings within the tube, and all magnetiſm diſappears.

How far theſe obſervations and experiments go, to eſtabliſh the doctrine of a magnetic effluvium flowing through the earth, or from one end of a magnet to the other, muſt be left to the reader's judgment and opinion. We are apt to laugh at the *ſubtil matter* of Des Cartes, and the *æther* of Euler, as occult qualities, which modern philoſophy will not admit into its creed. But this effluvium is a ſubtil matter, an æther, equally as inexplicable, and as equally out of the reach of our five ſenſes to ſcrutiniſe; but if we may venture to gueſs at cauſes by effects, and to compare analogies with what we can ſee, feel, &c. I think we have infinite data in favour of an electro-magnetic fluid, ſuperior to any proof that can be brought of æther being the cauſe of gravity, light, viſion, &c.

SECTION VI.

Miſcellaneous Obſervations.

SMALL magnets have a ſtronger attractive power, in proportion to their ſize, than large ones; and ſometimes a piece broken off a ſtone magnet will be ſtronger than the ſtone itſelf: ſhewing the ſtone not to be homogeneous, but that ſome parts of it are more ſuſceptible of magnetiſm than others.

Magnetic power may almoſt be ſaid to be created by friction, rather than communicated by it; for a magnet acquires ſtrength by giving magnetiſm to iron; ſo that if all the magnets in the world were loſt, magnetiſm might be revived, by rubbing the end of one ſteel bar againſt the ſide of another.

It is highly probable, that the near approximation of ſteel, or iron, to the texture of the ſtone magnet, is the reaſon why ſome iron is more ſuſceptible of receiving and retaining this virtue than others.

Unimpregnated iron attracts the magnet as forcibly as the magnet attracts it; (for iron ſeems to ſolicit the union by as forcible efforts as the magnet itſelf). Hence, if a magnet be made to ſwim in a little boat, and a piece of iron be held ſtationary, at a little diſtance from it, the boat will move to the iron.

One magnet attracts another, with leſs force than either attracts iron: but the two magnets will influence each other at a much greater diſtance.

The north pole of a magnet, properly ſuſpended, always points towards the north magnetic pole of the earth; and *vice verſa*; and in the time of the aurora borealis, in the direction of its rays: and an heavy ſteel bar loſes of its weight, when magnetized.

Files, and other hard ſteel tools, acquire temporary magnetiſm by their friction or colliſion with iron.

Magnets loſe their power by length of time, if left without thoſe conductors, or pieces of iron, which form the magnetic circuit. For horſe-ſhoe magnets require but one, as *q*, fig. 10, Plate VII.; but bars require two, as fig. 8, Plate VI. the bar *a* lying with its marked, or north, end *e*, in a contrary direction to the bar *b*, whoſe north end is at *f*. The conductors are *c* and *d*; ſo the bar *a* delivers its effluvium at *e*, to the conductor *c*; and the bar *b* delivers it at *f* to *d*; forming the magnetic circuit. In theſe poſitions, and in this ſtate of equilibre, magnets retain their virtue for ages; and if, by accident, their virtue becomes impaired, it may be eaſily regained, by hanging a bag to its conductor, and increaſing its weight with ſhot or ſand.

Artificial magnets, made of hard tempered ſteel, are much ſtronger than natural magnets, and communicate the magnetic virtue more powerfully.

Flat bars, about one eighth of an inch thick, receive and retain magnetiſm better than when thicker; becauſe, in hammering thick pieces, the interior parts cannot be arranged in the ſame manner as the outſide, but muſt form a reſiſtance to the paſſing fluid.

Fire and ruſt injure the virtue, by confuſing the direction, of the magnetic ſtream.

If a natural magnet be broken into any number of pieces, each piece will have an attracting and a repelling pole; and the middle part, between the poles, will neither attract nor repel.

If a ſteel ſewing-needle be rubbed, from its eye to its point, a few times over the north (or marked) pole of a magnet, and then ſtuck in a ſmall cork, to ſwim in water; the eye will point to the north, and the point to the ſouth. This forms the Chineſe compaſs.

Magnets exert their greateſt power at their ends; for the wiſe purpoſe of catching conductors, to form the magnetic circuit.

If a piece of common iron be held to *one* end of a magnet (ſo that the grain of the iron and the magnet be in the ſame direction), the other end will lift more than it would otherwiſe.

The attraction and repulſion of magnets is not diminiſhed by the interpoſition of any other body. Small ſewing-needles may be made to dance on a table, by moving a magnet under it. Many magic pictures are made, and curious queſtions anſwered, by devices formed on this principle.

Whatever deranges or diſturbs the pores of a magnet, injures its magnetic force; ſuch as ſtrokes from a hammer, or other violent percuſſion, &c.

When ſmall bars of ſoft iron are applied to the two poles of a natural magnet, and fixed there by thin plates of braſs (called armour), as fig. 9, Plate VI. where *a* is the natural magnet, *b* and *c* the bars, the effluvium flowing all round the magnet, from one end to the other, is diverted through the conductor *e*, which will ſupport a much greater weight than the natural magnet unarmed.

Many ſubſtances ſeem ſlightly attracted by the magnet, beſides iron; but it is known that almoſt every animal, vegetable, and mineral ſubſtance, contains iron; and hence they appear to be affected by the magnet.

A piece of iron held near a magnet, becomes a magnet itſelf for the time; and that end neareſt the magnet acquires a contrary polarity; that is, one delivers, and the other receives, the effluvium, for iron muſt receive magnetic virtue before it will be attracted.

If two magnets approach each other, with poles of the ſame name, they are mutually repelled at a ſmall diſtance; but if brought into contact, they attract and ſtick together: for a ſtronger magnet will change the poles of a weaker, the inſtant they touch each other; like ſtronger light abſorbing, or turning back, weaker.

SECTION VII.

On the Variation of the Magnetic Needle.

TO enumerate all the theories that, at different periods, have taken place about this myſterious phænomenon, would fill a volume. I reject the internal loadſtone of Halley, becauſe neither experimental nor analogical proof can be had of its exiſtence; and its four poles account no better for the variation, than the two poles of Euler. Simplicity is dictated by nature, and I adopt its ſuggeſtions. Obſervation muſt be our guide.

Before any rational theory can be formed, we muſt premiſe a few poſtulata, that ſeem to lead to it. Firſt, heat weakens the attractive power of all magnets. A compaſs-needle has a periodical revolution by the heat of the day, and cold of the night; it will increaſe in variation from eight in the morning, till about one, then become ſtationary for ſome time, and before morning return to its firſt poſition. In the winter, this variation is about 6 or 7 minutes of a degree; in the ſummer, about 13 or 14′. This proves that heat is concerned in the general variation of the compaſs. 2d. The whole ſpace included in the arctic and antarctic circles, may be ſaid to be nearly *round planes*, with their edges preſented to the ſun; his rays falling, therefore, ſo oblique, and in ſo ſmall a quantity, on theſe frigid zones, muſt occaſion their exceſs of cold: but cold aſſiſts magnetic attraction; and as the baſer metals are found more towards the polar than the torrid regions, iron is probably in greater abundance there, and may determine the place of entrance, or exit, of the earth's magnetic ſtream, and of courſe determine the place of its poles. For iron (even in a metallic ſtate) is found, in moſt parts of the globe, in greater abundance than all other metals: and bar-iron acquires magnetiſm by ſtanding parallel with the dipping-needle in all parts of the globe, as iron filings do by lying in the effluvium of a common magnet. This proves the earth itſelf to be a magnet. A ſtrong ſhock of electricity paſſing through a piece of iron, will give it temporary polarity; but paſſing through hardened ſteel, the ſteel will acquire fixed polarity and magnetiſm. A ſtroke of lightning has, in like manner, given polarity to iron and ſteel; has made many ſewing-needles to ſtick together; and has changed the poles of the compaſs-needle. The aurora borealis alſo affects the needle with tremor and vibration, making it point towards the centre of the aurora: reinforced by many other reaſons, theſe prove lightning, electricity, and the aurora, to be all of the ſame nature, or electricity. If electricity, light, and fire, be but modifications of one and the ſame principle (as I hope will be proved hereafter), and they have their origin, or fountain, in the ſun, it is natural to ſuppoſe, in iſſuing from that luminary, they proceed from him firſt in their pureſt ſtate, or in the character of electricity; that joining the particles of our atmoſphere, electricity becomes *light*, and uniting with the groſſer earth, *fire*. The lower region of the atmoſphere is an electric, or non-conductor, when very free from moiſture; but the air, rarefied on an air-pump, till it becomes of the ſame rarity, or thinneſs, as the upper region of the atmoſphere, is a conductor of electricity. Hence the difficulty electricity has in making its way through the lower air (after that air has been ſome time dried by hot weather), exhibiting thunder and lightning; and hence the eaſe with which electricity glides through the upper air towards the poles, in the character of an aurora. This idea may be better underſtood by fig. 16, Plate VIII. where *A* repreſents the ſun's rays falling on the upper air at *c c c*, and penetrating it as a conductor. At *d d* they penetrate directly, and forcing their way into the lower air, occaſion thunder and lightning by it reſiſtance, when that air is not moiſt enough to conduct the lightning to the earth. Hence the ſuper-quantity of thunder and lightning in the torrid zone, than in the other parts of the earth. Motion being rectilineal, all matter in motion ſtrives to go forward in ſtraight lines, and the eaſieſt way: the conducting part of the polar atmoſphere is in a line with the ſun's rays, as *c m*, and *c g*; and the parts *i i* approach ſo near to the ſame direction, that it will be eaſier for theſe rays to ſlide down the conducting parts *c i*, towards the poles, than puſh into the non-conducting parts *a a*. Hence a condenſation of electricity muſt take place near or about the poles, and occaſion the aurora borealis, and aurora auſtralis, as at *r* and *s*; for when electricity is condenſed to a certain degree, it always becomes viſible. In this figure, the northern hemiſphere of our globe is preſented to the ſun, as it is at our midſummer; and muſt, from its poſition, receive, within the arctic circle, more electricity from the ſun, than can be received within the antarctic circle. May not the ferruginous matter of the earth conduct this ſuperabundant poſitive quantity to the other pole, now in a negative ſtate, and produce the horizontal aurora, ſeen ſtreaming upwards towards a point, and generally in the north-weſt?—And is not this the reaſon why the ſtreamers are ſeen only in the winter, or about the equinoxes? Electricity excites to more vigorous exertion the living principle of both plants and animals; excites quicker motion in fluids; excites the heart to a ſwifter pulſation: and may it not excite the latent, though inherent, principle of magnetiſm in iron?—(for friction calls forth magnetiſm, as well as electricity). The act of making a bar-magnet by rubbing, gives it electricity enough to affect a ſenſible electrometer. Electricity may be drawn from every kind of ſubſtance on the earth's ſurface; and the earth has, therefore, been called the grand reſervoir of it: no doubt but it is diffuſed through the general body of the earth, and poſſeſſes thoſe bodies moſt, to which it has the moſt affinity. Now iron being more abundant in the earth than all other metals, and proved to have affinity with, and to be a conductor of, electricity; and electricity having the property always to endeavour at an equilibrium, wherever it is in a condenſed or rarefied ſtate; if the north polar regions be in a condenſed ſtate in ſummer, and the ſouth in a negative or rarefied ſtate, and *vice verſâ*, then will there be a circulation through the globe between theſe polar regions, that may arrange the ferruginous parts of it into a magnetic axis, like the lines of variation, ſerpentine as *x x*, fig. 16, Plate VIII. or, perhaps, in the order they are really found to be, as in fig. 17, Plate VIII. As the northern hemiſphere is expoſed to the ſun eight days longer every year than the ſouthern, and as the extremes of heat and cold are much greater in the latter (ſee Aſtronomy), may not this be the reaſon why the ſouth magnetic pole is farther from the ſouth pole of the equator, than the north magnetic pole is from the north pole? For it is conceived that the north magnetic pole is ſomewhere near the arctic circle, and ſuppoſed by ſome to have a regular rotation round it, in a certain period of years; ſome think from eaſt to weſt, and ſome from weſt to eaſt: ſome affirm it regular, and calculate on that regularity; but more are convinced it is not regular: ſome argue that capes and iſlands retard its motion, and, therefore, that the north and ſouth magnetic poles are not antipodes to one another; for the ſouth magnetic pole ſeems, by the effect it had upon the needle of Captain Cook's compaſs (which turned ſeveral degrees in one day's ſailing), to be about 144½° eaſt long. and 59° ſouth lat. By other accounts, it ſeems to be in 130° eaſt long. and 66° ſouth lat.; and others place it 165° eaſt long. and 60° ſouth lat.; ſo that it ſeems to ſhift backwards and forwards with too much irregularity, to form any theory of its cauſe, ſituation, or motion.

That a line, on every part of which the needle points due north and ſouth, does run ſerpentine between thoſe two magnetic points, is more than probable; for ſuch a line is found near Cape Florida, running through the Bahama and Leeward Iſlands, paſſing over part of Guiana and Brazil, where it again enters the Atlantic Ocean, and is believed to paſs over the real ſouth pole to the ſouth magnetic pole *c*, as denoted by the ſpotted line *a a*, fig. 17, Plate VIII. On the eaſt ſide of this line, the variation is *weſt*; on the weſt ſide, the variation is *eaſt*. Another line of no variation is alſo ſuppoſed to originate at the north magnetic pole *d*, and to paſs over the real north pole; after which it is really found to run through Siberia, Tartary, China, and the Eaſt-India Iſles, along *b*; and from thence ſuppoſed to the ſouth magnetic pole *c*. On the eaſt ſide of this line the variation is *eaſt*; and on the weſt ſide, *weſt*; agreeably to the figures, ſhape, and diſpoſition, of the ſerpentine lines on the hemiſpheres, fig. 17, Plate VIII.

Notwithſtanding the irregular motions of theſe poles, and the lines of variation iſſuing from them, there are conformities that would ſeem to lead to a rule or theory. The line of no variation in 1700, paſſed from about Charleſtown, South Carolina, north of the Bahama and Leeward Iſlands, ſerpentine towards the coaſt of Africa; by which it paſſed about one third of the diſtance between that coaſt and that of South America, towards the ſouth pole. Since that time, it has moved irregularly towards the weſt 30°, but ſo as to keep nearly parallel to itſelf; carrying the eaſt and weſt lines of variation along with it. This ſeems as if the magnetic poles had a motion from eaſt to weſt; though ſome affirm their motion to be from weſt to eaſt: an hypotheſis which has but one obſervation, to ſupport it, that can be much depended upon, viz. that the line of no variation paſſed over London in 1657, and not over Paris till 1666. But the imperfection of needles, and of obſervation, at that time, might occaſion this opinion; for as the lines of variation do certainly move weſtward, there can be little doubt but the magnetic poles move the ſame way.

It has been ſuppoſed, that the aurora, or northern lights, have the centre to which they generally tend, over, or in the zenith of, the north magnetic pole; and, therefore, when that is beneath our horizon (in its rotation round the real pole), thoſe lights muſt diſappear to us; and from thence may be inferred a reaſon for the vulgar opinion, that the ſtreamers were never ſeen till the year 1714. In the writers of the dark ages we frequently read of armies ſeen fighting in the air, as portents of ſome impending wars, or other calamities: there can be little doubt but theſe were northern lights. However, there ſeem intervals in the appearance and non-appearance of this ſtriking phænomenon; it has not been ſeen remarkably in England for ſeveral years; and if it could be proved that it followed the north magnetic pole, or was influenced by it, this would be a grand ſtep towards aſcertaining its period.

That theſe lights are electricity, many other proofs might be adduced. Light from fixed ſtars is not refracted, or bent, in its paſſage through the aurora; neither is the light from a candle, or any other luminous body, refracted or bent in paſſing through the flames of electricity. Both the aurora and electrical light, viewed through the priſm, exhibit the ſame colours as a ray from the ſun, &c.

SECTION VIII.

On the Dipping-Needle.

LET a bar of hard ſteel, fig. 12, Plate VII. (unimpregnated with magnetiſm), be ſuſpended horizontally between two nice points, ſo as to hang in equilibrio: if then it be touched, as before directed, and again ſuſpended, it will be found to have loſt its horizontal balance: in this part of the world it will incline, ſo as to form an angle with the horizon, of near 73 degrees; further north, it would incline more; and probably over the north magnetic pole it would ſtand perpendicularly. Such needles, taken into various parts of the world, dip as in fig. 14, Plate VII. On the magnetic equator *a b*, the bar would hang horizontally; at *c*, it would dip as fig. 12, Plate VII.; at the north magnetic pole *d*, it would ſtand like the lines, perpendicularly: i. e. at *a* or *b* it would be ſo equally acted upon by both the north and ſouth pole, as to obey neither; but as it approached *c*, its ſouth pole would point through the earth towards the north magnetic pole, and incline in an angle equal to the complement of the angle 73°, mentioned above; and if perfectly at liberty, ſo as to turn in any direction, it would form itſelf parallel to the luminous beams of the aurora borealis; for that point in the Heavens to which the beams of the aurora appear to converge at any place, is the ſame as that to which the ſouth pole of the dipping-needle points at that place, when the aurora is ſtrong, and points to a centre.

If a loadſtone be ground into a globe, the ſame dip and inclinations will take place upon it as upon the real earth: ſee fig. 15, Plate VII.; where *a* is the terella or globular magnet, and *b* a ſmall glaſs globe, blown at the end of a capillary tube *c*. If a quarter of an inch, broken off the ſmall end of a ſmall ſewing-needle, be put into the bulb *b*, and the bulb be ſlid over various parts of the terella; in two places, the bit of needle will be found to ſtand perpendicularly on its ends: theſe places on the terella are its poles. The needle moved ſlowly from one pole to the other, will firſt incline a little, then more, till it is half way between them, or at the magnetic equator; there it will lie horizontally on the globe: on being moved forward, its lower end will begin to be elevated, and will become more and more ſo, till it arrives at the other pole, when it will ſtand perpendicularly on the contrary end. This is preciſely ſimilar to what happens to the dipping-needle, when carried to various parts of the earth; and, therefore, the globular magnet is properly called a *terella*, or little earth. Filings ſtrewed on the terella, will exhibit the ſame appearance; and if its magnetiſm has not been diſturbed or deranged, by lying with, or near, other magnets, the filings will appear on it like fig. 14, Plate VII. Otherwiſe, the filings often appear in little tufts, indicative of a diſturbed magnetiſm; a circumſtance, no doubt, to which the earth itſelf is liable, from the magnetiſm of it being found different at the ſame place, after a ſhort ſpace of time. This, I think, indiſputably proves the earth to be magnetical.

SECTION IX.

Magnetic Amuſements.

1. HOLD the north pole of a magnet *near* the ſouth end of a ſuſpended needle, and the needle will become agitated; and, with a vibratory motion, ſeem wiſhful to approach the magnet, for about half a minute, when the magnetic ſtream will become alike in both, and then the needle will be at reſt.

2. A tee-totum in motion, will be taken up by a magnet, as if at reſt; and one or two more will hang to the firſt, though they turn in contrary directions. Young people are much entertained, by ſeeing a tee-totum ſpin on its head, as well as on its foot.

3. The figure of a ſmall ſwan, with an iron bill, may be made to ſhew its fondneſs for bread, and averſion to cheeſe, by ſticking a piece of bread (with a wafer) on the north pole of a magnet, and a piece of cheeſe on the ſouth pole; the ſwimming ſwan will follow the bread round a baſin; but, on turning the cheeſe, he ſwims from it.

4. The figure of a ſmall fiſh, having a piece of iron in its mouth, will follow a hook of ſteel magnetized, round a baſin of water; and may be lifted out of the water by it.

5. The iron coffin of Mahomet is ſaid to be ſuſpended in the air, by a powerful magnet. A ſmall coffin, made of very thin ſheet iron, and faſtened to a table by a black horſe-hair, will ſeem

to hang under a magnet, as if without ſupport; ſo that a quill, or ivory knife, may paſs between the coffin and the magnet.

6. If in a pond of water, of about an inch in depth, and eight inches diameter, the above ſwan be placed, and on the edge twelve hours be marked, as on a clock face; and then a watch, having on its hour centre a light magnet fixed, be placed cloſe under the thin braſs bottom of the pond; when the ſwan is put in the water, it will ſwim to the hour and minute of the day, and tell the company what o'clock it is.

7. The divining circles are drawn on paper, paſted on the top of a thin box, *A B*, fig. 18, Plate VIII. The index *a* is fixed on the axle of the toothed wheel *c*, which works into the pinion *d*. On the axle of *d* is another pinion of the ſame number of teeth, that puts in motion the wheel *g*, of the ſame ſize and number of teeth as the wheel *c*. On the axle of *g* is fixed the bar-magnet *q q*, and they turn together. Over this axle (but independent of it) is fixed a point for the looſe needle *x x* to turn upon, and which is the centre of the paſted circle *F*. In the compartments of this circle are written anſwers to the queſtions aſked in the compartments of the circle *G*. A carton of ſtrong paper, of the ſize of *F*, ſhould cover the paſted circle, and turn eaſily on the centre *z*: it ſhould have one of the triangular pieces, as *F*, cut out, in order to ſee the anſwers. If then the needle be taken off its point, and a perſon wiſhes to aſk ſome of the queſtions on the carton *G*, the perſon muſt turn the index to the queſtion, and then place the needle on its point, giving it a whirl round, when it will ſtop over the anſwer. The open part of the looſe carton being turned to that place, will exhibit the anſwer.

LECTURE III.

MECHANICS.

SECTION I.

On Gravity.

IN the laſt lecture we endeavoured to give a general idea of the leading laws of nature; in this, its mechanic laws ſhall be more particularly conſidered. The attraction of coheſion, that wonderful power, by which the atoms of matter draw together, cohere, and maintain diſtinct forms, we hope was fully explained. But this principle is of much more extent and influence than appeared in that lecture; for we have many proofs to offer, that gravitation itſelf is but the attraction of coheſion upon a larger ſcale. By gravity, we mean that tendency all matter has towards the earth's centre: it is weight; and has been ſuppoſed to ariſe from an attracting ſomething placed at the centre. But the following experiments tend to prove, that the whole globe itſelf is the attracting body, and not any thing placed at its centre. A pound of lead, and 200 yards of packthread, were put in one ſcale of a balance, and the ſame weight of lead and length of packthread were put in the other ſcale—they balanced each other. But when one of the plummets, ſuſpended by its 200 yards of packthread, was hung in the ſhaft of a coal-pit, of that depth from its ſcale, they did not balance each other; that in the coal-pit was lighter. Now, as the air is more denſe at the bottom of ſuch a pit, than at the top, it is natural to ſuppoſe its greater buoyancy might occaſion the difference; but when allowance was made for that, ſtill there was found a want of weight in the ſuſpended plummet, that could not be accounted for, but from the attraction of the 200 yards maſs of earth above it. This maſs certainly bears but a trifling proportion to the maſs below it; but its attraction (on account of its vicinity to the plummet) will be ſeen hereafter to be a ſufficient cauſe for the loſs of weight in the plummet.

2d. A mountain was ſelected in this iſland, for the purpoſe of ſuſpending the plumb-line of a zenith-ſector, from the top of an high precipice. The plummet evidently inclined towards the mountain, out of a perpendicular. The ſame experiment was made over a ſimilar precipice, on the other ſide of the mountain; and ſtill the plummet was found to be attracted towards the mountain. A ball, nicely ſuſpended, was hung near a huge body of lead, and ſo incloſed that heat, cold, or motion, in the air could not affect them; and the ſmaller body was attracted to the larger. Do not theſe experiments ſhew the whole body of the earth to be the attracting body, and the cauſe of weight? This mighty principle forms the earth into a round and denſe ball, holds every thing animate and inanimate to its ſurface, and makes its whole ſurface its general top! By this do we ſtand faſt on all ſides of the globe; for the thickeſt maſs of earth is directly under our feet, wherever we ſtand; and the thickeſt maſs has the moſt powerful attraction, acting upon all bodies according to this law. If I let a ſtone drop from my hand, I ſay it is the attraction of the earth, that draws the ſtone to the earth. But if I let a ſtone drop from the top of St. Paul's cupola, I find it is accelerated in its deſcent, going faſter and faſter: i. e. it will fall about 16½ feet, or a rood, in the 1ſt ſecond of time; it will fall three roods in the 2d ſecond; five roods in the 3d ſecond; ſeven, in the 4th ſecond, &c. agreeable to the odd numbers 1, 3, 5, 7, 9, 11, 13, 15, &c. Why ſhould the body be accelerated?—The power of gravity is as great on the top as on the bottom of St. Paul's; nay, we find little difference in this power, between the tops of the highteſt mountains, and the deepeſt pits. There is a principle, Newton calls *vis inertiæ*, which, I think, clearly explains this; but let us firſt enquire what it is. Every one muſt obſerve a ſluggiſhneſs in all kinds of matter; that when it is at reſt, it endeavours to continue at reſt; and when in motion, it inclines to continue in motion. No doubt, if I lay a ball on the ground, it would lie there for ever, if ſomething did not put it in motion: and if I kick it with my foot, it would run or fly for ever, if there was no impediment to ſtop it. If I puſh a bowl of water with my hand, the water flies over the edge of the bowl upon my hand; for it endeavours to continue in the ſtate of reſt it was in. But if I take up the bowl, and running away with it, ſtop of a ſudden, the water flies forward the way I was running; from its *vis inertiæ*, or tendency to continue in the ſtate of motion it was in. Lay a guinea on a ſmall card, and both on your finger; the ſmart ſpring of your fore-finger againſt the edge of the card, will drive away the card, and leave the guinea on your finger: the *inertia* of the gold is the cauſe. Hence the difficulty of putting heavy bodies into motion, and of ſtopping them when in motion. Why do I run my head through the fore-glaſs of my carriage, when it accidentally runs againſt a poſt? My body is ſubject to the ſame law as the moſt inanimate matter; and endeavours to continue in the ſtate of motion I was in, before the carriage ſtruck the ſpot. The word *endeavour* applied to inanimate matter, calls forth the feeble criticiſms of minor philoſophers; but certainly all that was meant by it by the great Newton, was what we may ſee every moment, viz. the *tendency that all matter has to continue in the ſtate it is in, whether of reſt or of motion.* But how is this *vis inertiæ*, you will ſay, to account for the accelerated deſcent of falling bodies? If it is the power of gravity that pulls the ball from the top to the floor of St. Paul's, let us ſuppoſe that gravity to ceaſe, juſt when the ball had fallen half way: now the quantity of motion it had acquired in that deſcent, would carry it forward, though gravity had ceaſed there, and that by its *vis inertiæ,* or endeavour to continue in that ſtate of motion it was in. As this law, like gravity, never ſleeps, this power muſt operate upon the falling body every inch of its deſcent, and of courſe increaſe its motion. The air forms a reſiſtance to falling bodies; and, therefore, under any other retardation, no doubt the ſame rule will hold good: an iron ball will fall about a rood or 16 feet in the firſt ſecond of time; it will fall three roods in the 2d ſecond, &c. and if, by a counterbalance, it falls but a foot in the firſt ſecond, it will fall three feet in the 2d ſecond, five in the next, ſeven in the next, &c. as may be proved by hanging two balls, of unequal weights, by a long thread over a pulley; for by the ſlowneſs of the ball's deſcent the reſiſtance of the air may be conſidered as nothing. The pulley ſhould reſt on friction wheels, as fig. 1, Plate V. *Mechanics,* to render the friction as little as poſſible. If now the heavier ball *a* have its centre brought even with the top of the ſcale, and the pendulum *c* be drawn on one ſide, till the looſe hammer *d* ſtrikes the bell *o,* and both the ball and pendulum be let go at that inſtant, then will the ball *a* ſtrike the ſtage marked 1, at the ſame inſtant the hammer ſtrikes the bell *w*; ſhewing that it falls one in the firſt ſecond of time. If now the ſtage 1 be taken away, and the ball and pendulum be put in the ſame poſition as before, and let go at the ſame inſtant, there will be a ſecond ſtroke on the bells, the inſtant the ball *a* ſtrikes the ſtage 3; or, in other words, there will be two vibrations of the pendulum while the ball has fallen four, the ſquare of that time. If now the ſtage 3 be taken away, and the pendulum and ball be put in the ſame poſition as at firſt, the bells will ſtrike three the inſtant the ball ſtrikes the ſtage 5, &c. ſhewing the ball to have fallen through nine ſpaces in three ſeconds, and that the fall of bodies is as the ſquares of the times: and which may be well repreſented by the endleſs triangle, fig. 2, Plate V. *a* 5 *b*, where 1, 2, 3, 4, 5, &c. repreſent the times, or returns, of the pendulum *d c*. Fig. 1, Plate V. *Mechanics*, *a* is a plummet a little heavier than *b*, ſo as to fall from *a* to the firſt figure of the ſcale, marked with the large figure 1; this it performs in one ſecond of time, or while the pendulum *d c* makes one vibration. In the next ſecond, it will fall from 1 to 3 of the large figures, or from 1 to 4 of the ſmaller; i. e. it will fall the height of three of the diviſions in the 2d ſecond of time. In the next ſecond it will fall 5 of the diviſions; in the next, 7, &c. agreeable to the odd numbers, 1, 3, 5, 7, 9, 11, 13, &c. So that we find another corroboration of the idea, that the ſquares of numbers was in the Almighty Mind at the creation of all things. Here we find at the end of the 3d ſecond of time the ball has fallen nine; at the end of the fifth ſecond, it has fallen twenty-five; at the end of the ninth ſecond, it has falled eighty-one, &c. the ſquares of the times.

This law equally holds in the fall of projected bodies. If I throw a ſtone horizontally, it falls to the ground in a curve of the parabola, and as faſt as if I let it drop from my hand; and by the ſame rule as the foregoing. It ſeems a bold aſſertion to ſay, that a cannon, diſcharged horizontally on the top of a tall tower, ſhall throw a ball two miles diſtant; and that it ſhall ſtrike a level plain, or the ground, at the ſame inſtant that another ball, let fall from the muzzle of the gun (the moment of its diſcharge), ſhall ſtrike it! But there is no doubt of the fact; for though the projected ball may ſeem to move point blank (and bid defiance to the power of gravity half its way), it will perform *that half* in ſo ſhort a ſpace of time, that it will fall a rood in the 1ſt ſecond, as from *a* to *c*, fig. 3, Plate V. *Mechanics*; three roods in the 2d ſecond, like other falling bodies; for an horizontal impulſe retards not the power of gravity, in reſpect to time. I have a groove in the board *a*, fig. 2, Plate IX. from *b* to *c*; it is made cycloidal, as being the line of ſwifteſt deſcent; down this groove, I let fall a child's marble, and it flies through the rings *d*, *f*, *g*, deſcribing the ſemi-parabola *c r*. But at *c*, the ball ſtrikes a feather which lets fall the ball *q*; the balls *r* and *q* ſtrike the horizontal level *s r* at the ſame inſtant.

This may be ſtill more mechanically repreſented by fig. 3, Plate V. *Mechanics:* for as bodies that are acted upon by two contrary or oblique forces, obey neither; ſo, as above, we ſee the power of gravity endeavouring to pull the ball down to the ground, while the gunpowder impels it horizontally; it obeys neither, but a medium, or diagonal of the two. Let *a* repreſent the gun, *c d* the horizontal diſtance, or the power of the gunpowder in the firſt ſecond of time; *c e* the power of gravity; the ball obeys neither, but deſcribes the diagonal, or medium, *c g*. When at *g*, the impulſe of the powder would force it along the line *g h*, but, counteracted by the power of gravity, it falls down to *n*, &c. thus falling in the above ratio, 1, 3, 5, 7, 9, &c. while the retardation of the ball by gravity, and the reſiſtance of the air, is repreſented by the numbers 10, 9, 8, 7, 6, &c.* This propoſition, though the foundation of the art of gunnery, is not ſtrictly true. Robins has found the ſtates of the air, the different ſtrengths of gunpowder, and other circumſtances, take off a little from its correctneſs, though the theory is ſtrictly juſt; as will be ſeen, when we apply this ſublime law to the explanation of planetary motion. Bodies thrown upward, are retarded in the ſame ratio as they are accelerated in their deſcent: and it is a pleaſing circumſtance, to ſee how the greateſt and the leaſt things in nature are regulated by the ſame ſimple laws! Is it not wonderful, that the ſame law which brings the ſtone to the ground, which I throw from my hand, ſhould be that by which the moſt magnificent of all machines is regulated, viz. the ſolar ſyſtem? If *A* repreſent the earth, and *B* the moon, fig. 1, Plate IX. and we find that her orbit *N* is an oval, or which may be ſaid to be nearly made up of the curves of the parabola, and that ſhe falls from a tangent, *B r*, to her orbit, agreeable to the odd numbers 1, 3, 5, &c. we cannot doubt but ſhe obeys the ſame law as the common projectiles on the ſurface of the earth.

1ſt. That bodies which are acted upon by two or more forces, obey none of them ſingly, but a medium of all the forces, is proveable in many familiar inſtances. Let *a* be a billiard ball, fig. 10, Plate IX. and ſtruck by two cues, *b* and *c*, at the ſame inſtant; *b* would impel it in the line *e*, and *c* in the line *d*; but both will impel it along the line *f*, the diagonal or medium between *d* and *e*.

2d. If a leaden ball be dropt from the maſt-head of a ſhip, under

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* A writer of eminence ſays, "Gravity does not retard a ball's advance."

ſwift ſail, one would think, before the ball would reach the deck, the ſhip would be ſlid from under it, and that it would fall behind the ſhip into the ſea. This is not the fact; for the ball falls down by the ſide of the maſt, as if the ſhip were at anchor. Why? Becauſe the ball is under the influence of two forces; one horizontal, by the motion of the ſhip; the other perpendicular, by the power of gravity: ſo that though it appears to fall perpendicularly, it does not, but deſcribes, in ſpace, the ſame kind of ſemi-parabola as the aforeſaid ball ſhot from a gun.

3d. If I throw a log of wood into the Thames, when the wind is acroſs the river; the log will not obey the current, by going down the river, nor the wind, by going acroſs the river, but a ſloping direction made up of the two. The motion of a cannon ball, diſcharged with 1-3d its weight of powder, is nearly equal to the motion of any point in the earth's equator. When therefore the ball is diſcharged eaſtward, its motion is *doubled*, by the motion of the earth; when to the weſtward its motion (in regard to ſpace) is *nothing*.

Pendulums obey the power of gravity reciprocally, as the ſquare roots of their lengths; *i. e.* a pendulum four times as long as another, will vibrate half as faſt; and one nine times as long as another, will vibrate but one-third as faſt, &c. whatever may be the weight of their bobs. If the bob *a*, fig. 7, Plate V. be ſuſpended by the thread *a b*, and let go at *a*, it will fall to *d*, and riſe to *c*. This is called an oſcillation. At *d*, the bob will have acquired the ſame velocity, as if it had fallen perpendicularly from *g* to *d*; and that quantity of motion will carry it up to *c*, by the forementioned law of *vis inertiæ*. In this arc it would move for ever, but for the friction at the point of ſuſpenſion *b*, and the reſiſtance of the air. Hence pendulums becomes ſo uſeful in meaſuring time; for a pendulum of 39.2 inches, will vibrate an aliquot part of the time the earth is in turning upon its axis: *i. e.* $\frac{1}{86400}$ part; or make ſixty oſcillations in a minute. When we ſay that a pendulum of 39.2 inches will vibrate ſeconds, this muſt not be underſtood as holding good in all parts of the world: every thing grows lighter as we approach the equator, and heavier as we approach the poles, from the greater centrifugal motion at the equator (occaſioned by the diurnal rotation of the earth), which, according to ſome is equal to $\frac{1}{289}$ part of gravity. Hence a pendulum of 39.2 inches would vibrate too ſlow near the equator, and too faſt towards the poles*. And as we have ſeen, by the pyrometer, that metals expand by heat, the rods of pendulums grow longer in the torrid zone: contributing alſo to the irregular going of clocks and time-keepers.

The length of a pendulum is from its point of ſuſpenſion to its centre of oſcillation; which centre is near the centre of gravity of the bob, if the rod be very light. But if a rod of equal thickneſs, *c d*, fig. 4, Plate IX. (without a bob), be made a pendulum, its centre of oſcillation is at two thirds of its length from the point of its ſuſpenſion; and it will vibrate in the ſame time as the pendulum *a b*, fig. 4, Plate IX. The quantity of motion in the part *c e*, being equal to that of *a b*, if the point *e* be ſtopt by any obſtacle, the whole motion of the rod will be ſtopt at once. Hence the centre of percuſſion in weapons, being the ſame as the centre of oſcillation, it becomes eaſy to know where the ſtroke would have the greateſt effect.

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* A body will fall 313 inches at Spitzbergen, in the ſame time that it fall 312 at Quito, near the line.

From this rod, a national ſtandard meaſure might be conſtructed; for a rod of 58.8 inches will vibrate ſeconds; but if it were the thouſandth part of an inch longer or ſhorter, it would not vibrate ſeconds. Here then is an invariable and eternal ſtandard: and why might not 58.8 inches be an ell, a yard, a fathom, or any other name? and a quarter of it, the depth and diameter of a buſhel? &c.

We ſay that all bodies have a centre of gravity, or a point on which they may be ſuſpended in every direction. We conſider the whole weight of the body, as if it were condenſed or concentrated in that point: if this point, therefore, be ſupported, the whole body will be at reſt; if not, it will always endeavour to fall the neareſt way towards the centre of the earth. I endeavour to balance my cane upon my finger; after ſome time, I find a place where neither end will preponderate: the part which reſts on my finger is its centre of gravity.

2d. I place the piece of wood, fig. 5, Plate IX. on the edge of a table, and from a pin at its centre of gravity, *a*, I hang the plummet *d*: the line of direction, *a d*, paſſes within the baſe or foundation; and therefore the body does not fall, though it leans over its baſe.

3d. *The centre of gravity always endeavours to get beneath the centre of ſuſpenſion.* I hang the above piece of wood on the pin *g*, fig. 6, Plate IX. and on the ſame pin the plummet *d*; the line of direction ſtill paſſes over the centre of gravity *a*.

4th. Hence the centre of gravity, of any regular or irregular plane figure, is eaſily found. Suppoſe the piece of board *A*, fig. 7, Plate IX. be ſuſpended freely on a pin from the hole *A*, and on the ſame pin be hung the plummet *g c*, and its direction be marked on the board. Now remove the pin and plummet to *d*, and then the board will hang as fig. 8, Plate IX. and the plumb-line *d e* will croſs the firſt line *a c* at *g*, which is the centre of gravity of the board *A*.

In the motion of a chain-ſhot, if one ball be heavier than the other, they will perform a circuit round each other as they fly; but their centre of gravity will deſcribe a regular range, which will be a ſemiparabola. So the earth and moon, though they fly round each other in their annual journey round the ſun, neither of them deſcribe a regular oval round him: it is their centre of gravity that performs the real orbit.

5th. The tower *s a*, fig. 14, Plate V. has its centre of gravity at *a*: a plummet, *c*, let fall from it, and falling within the baſe, ſhews it will ſtand firm: but if *b* is placed upon it, the centre of gravity will be raiſed to *s*, and a plummet let fall from it, falls without the baſe; ſo they will both fall.

6th. The tower of Piſa, fig. 11, Plate IX. leans ſixteen feet out of the perpendicular: ſtrangers are afraid to paſs under it. But if its materials will hold together, there is no fear of its deſtruction; for let a plummet, *c*, fall from its centre of gravity, and it will be found to fall *within its baſe or foundation* (the ſteeple being nearly of the ſame thickneſs from bottom to top, and of courſe having the centre of gravity in the centre of the ſteeple): therefore it is no miracle why the ſteeple has ſtood 300 years, and may ſtand 300 more. Two towers at Bologna, one at Corfe-Caſtle, one at Caerphilly, in South Wales; a wall at Bridgenorth, and an hundred more, all aſtoniſh the vulgar; who conceive they muſt be kept up by ſome ſupernatural power! Not at all. There is nothing (well authenticated) that is ſupernatural in the order of the world. Nature is uniform in all her works; and it would be happy for mankind, if when they are amuſed with feats beyond nature, they would look out for cheat and impoſture.

The difficulty of ſuſtaining a tall body upon a narrow foundation is evident, when I attempt to balance my cane with its end on my finger, fig. 9, Plate IX.; *a* is its centre of gravity; now if I have not dexterity enough to keep the foundation on my finger, perpendicularly under the centre of gravity, the ſtick muſt fall. Hence ariſes the difficulties of the equilibriſt. This artiſt holds a long pole acroſs the rope on which he dances, with great weights at each end, and keeps his eye upon ſome object parallel to the rope; by which he can ſee when his centre of gravity is on this or that ſide of his ſlippery foundation, the rope; and by puſhing his pole on this or that ſide, he can keep his centre of gravity over the baſe.

7th. If a cylinder of wood, like a drum, with its centre of gravity at *c*, be placed on the inclined plane *a b*, fig. 11, Plate X. it will run down the inclined plane, becauſe that centre leans over the baſe *g* during its deſcent. But if I fill the hole *n* with a plug of lead, the cylinder will roll up the inclined plane, till the lead gets near *g*; and then the cylinder will be in a ſtate of balance, and lie ſtill on the inclined plane. Becauſe the centre of gravity is removed from *c* to *n*, by filling the hole *n* with lead.

8th. The double cone rolls up two parallel wires, though one end of them is conſiderably higher than the other, as fig. 12, Plate IX. But the centre of gravity of the cone is really at *a*, higher than at *c* and *d*. For as it rolls, it ſinks in between the opening wires, and is in reality deſcending, though it ſeems to aſcend.

9th. The rolling candleſtick, fig. 13, Plate IX. keeps the candle always upright, though rolled over a floor; for a weight *a*, beneath the candle, and alſo lower than the two centres of ſuſpenſion, *c c* and *d d*, will keep the candle perpendicular; for the centre of gravity always endeavours to fall beneath the centre (or centres) of ſuſpenſion. The circle *d c d c* hangs on two pivots, *e* and *f*; and the inner circle *o n* hangs on that circle by the pivots *d d*, at right angles to the pivots *e* and *f*. Theſe circles are called jimbals by ſeamen; and the compaſs being hung on the inner circle, keeps always horizontal, notwithſtanding the rolling of the ſhip; by which the magnetic needle can traverſe as freely as if its point of ſuſpenſion were fixed on ſhore.

10th. The nearer the centre of gravity and the line of direction coincide, the firmer any body ſtands on a plain. I ſtand firmer with my feet a little aſunder, than if they were cloſe. I lean forward when I have a load on my back, and backward when I have it on my breaſt. When I riſe from my ſeat, I lean my body forward, and draw my feet back: in all theſe caſes to bring the centre of gravity of my body over the baſe, my feet.

As the removal of great weights (or overcoming the force of gravity) is one of the great objects of mechanics, it is now time we ſhould explain the ſix mechanic powers, by which this and other difficulties are overcome. But we ſhould firſt be inſtructed in the momentum, or moving force, of machines or bodies.

1ſt. If the roller *a*, fig. 3, Plate IX. lean againſt the obſtacle *b*, it will be found incapable of overturning it: but if *a* be taken up to *c*, and ſuffered to roll down the inclined plane againſt *b*, it will overturn it. We call the ſtroke with which *a* ſtrikes *b*, its momentum; and that momentum is the quantity of matter in *a*, multiplied by its quantity of motion.

2d. We perform, in our days, greater feats with a ſmall bullet, than the ancients did with their huge battering ram. Suppoſe the ram, fig. 14, Plate IX. to be 27,360lb. weight; and, being ſuſpended by its centre of gravity *a*, from the ſupport *b*, that it could be influenced by manual ſtrength to move againſt the wall *K* at the rate of one foot in a ſecond of time; then its quantity of matter multiplied by its velocity would be 27360×1=27360, its momentum. Now if a bullet *c*, of 24lb. weight, be ſhot out of the cannon *g*, the ball will go as ſwift as ſound; and that is 1140 feet in a ſecond of time; ſo its quantity of matter, viz. 24lb. being multiplied by its velocity 1140×24=27360, its momentum, or moving force, againſt the wall *K*. Theſe two momenta being equal, their effect againſt the enemy's wall or gate muſt be equal; and ſhew that bodies may make out by velocity, what they want in quantity of matter, and *vice versâ*.

3d. *If a body falls upon any plane, from the height of about one inch and a quarter, it will ſtrike the plane with a momentum, equal to double its weight.* I immerſe the ſtick *a*, fig. 15, Plate IX. in a tall veſſel of water; and upon the wire *b* I ſlip two braſs balls, each one ounce: by their weight they will ſink the ſtick, ſo that the pin *c* ſtuck in it will juſt touch the edge of the veſſel. I now take off one of the balls, and the ſtick riſes out of the water a little: the remaining ball being then lifted up to *d* (one inch and a quarter above the top of the ſtick), and let fall on the ſtick, it will ſink it ſo much, that the pin *c* will juſt touch the top of the veſſel, as when both balls were on the wire. This experiment is made in water, to prevent friction.

4th. It is equally ſo with the heavieſt bodies: if I lift one hundred weight from the floor, one inch and a quarter, and let it fall, it will ſtrike the floor with a momentum equal to two hundred weight, &c. Hence may be calculated the momentum of any falling body from any height, as ſhells, pile-drivers, ſtrokes of hammers, &c.: for as the laws of nature ſeem to be regulated by the ſquares of numbers, if a falling body acquires a momentum equal to double its weight in falling one inch and a quarter, it will have twice that effect if its falls four times as high; three times that effect if it falls nine times as high; &c. &c. Let the light ſcale-beam *a c*, fig. 7, Plate X. have a hole at *c*, and a hook at *d*; let a wire *g* paſs through the hole, and be faſtened to the cieling of the room, tight. If this wire goes through one of the above braſs balls, as *d*, and it be let fall on *c*, from an elevation of one inch and a quarter, it will lift two ounces at *a*, and let go the ſlight ſpring *o*. If now two ounces more be hung on *a*, as *w*, and the ball *d* be let fall five inches, it will lift both weights, as will be proved by its diſengaging the ſpring *o*. If then the ball *d* be let fall 11¼ inches, it will lift three of the weights at *a*. If let fall twenty inches, it will lift four of thoſe weights; four times four making ſixteen, &c. &c. agreeably to the ſquare root of the heights.

5th. If I drop a ball into a pot of honey, and it ſinks to a certain depth in the honey, and then let it fall four times as high, it will ſink twice as deep in the honey; nine times as high, and it will bury itſelf three times as deep in the honey; &c. &c.

6th. If a ſhell of 50lb. weight were to fall from a height of ſeventy yards, according to theſe calculations, it would ſtrike the ground with a momentum equal to 4600 pounds.

7th. If a ſtone in the road reſiſts a light carriage with a force equal to one pound; if the carriage runs four times as ſwiftly over it, the ſame obſtacle will form a reſiſtance equal to two pounds; if nine times as ſwift, the reſiſtance will be equal to three pounds; &c. &c. I ſpeak here of a light carriage, becauſe an heavy one, when put in motion, has a *vis inertiæ* that will carry it over any trifling obſtacle, without any additional draught. This muſt alſo be underſtood of carriages that move with great velocity; for in a waggon, the ſlow motion obliges the horſes to overcome its *vis inertiæ* every moment of the draught; or as if the waggon were taken out of a ſtate of reſt every moment, into a ſtate of motion. Hence ſwiftneſs takes off greatly from draught; and if that ſwiftneſs did not fatigue horſes as much as draught, they would have leſs to draw the ſwifter they *went.*

Percuſſion, or colliſion, is but an illuſtration of that general law, that *action and reaction are equal.* If I ſtrike an anvil with a hammer, the anvil ſtrikes the hammer as forcibly as the hammer ſtrikes the anvil. If that anvil be large enough, a man may lay it on his breaſt, and ſuffer a ſtrong man to ſtrike it with a ſledge-hammer with all his might, without the leaſt pain or danger; for the *vis inertiæ* of the anvil reſiſts the force of the blow, and the man does not feel it. But if he had an anvil of no more than a pound weight on his breaſt, ſuch a ſtroke would kill him.

2d. Let *a* be a little cannon, fig. 1, Plate X. and *b* a hollow piece of iron or braſs, to ſlip on pretty tight upon *c c*, and of the ſame weight as *a*. Now if half a thimbleful of gunpowder be put in *a*, and *b* ſhut upon it, both being ſuſpended by ſtrings; if the powder be fired, the parts *a* and *b* will be thrown equally diſtant from *r*, the centre where they hung; ſhewing the reaction to be equal to the action. Hence an heavy gun ſeems to recoil leſs than a light one, on account of its greater *vis inertiæ*; otherwiſe its reaction is the ſame, with the ſame charge.

3d. Let two ivory balls be ſuſpended by threads, as fig. 2, Plate X.; if *a* be drawn a little out of the perpendicular, and let fall upon *c*, it will loſe its motion by communicating it to *c*, which will be driven to an equal diſtance to what *a* fell, viz. to *o*. By laying a little paint on *a*, if it touches *c*, it will make a ſmall ſpeck upon it; but if it *falls* upon *c*, the ſpeck will be much larger: ſhewing the balls to be elaſtic, and that a little hollow or dint was made in each by their colliſion. Theſe hollows being equal, their reaction muſt be equal, preſſing both balls alike in contrary directions. Therefore the ball *a*, imparting its half to *c*, will give *c* (with its half) the ſame momentum as *a*, and drive it to the ſame diſtance, *o*; while *a* loſes by the action and reaction its momentum, and becomes ſtationary. So if two ſoft clay balls met each other with equal velocities, they would ſtop and ſtick together at the place of their meeting, as having no elaſticity.

4th. But of three elaſtic balls, *c*, *a*, and *n*, hung from three joining centres; if *n* were drawn a little out of the perpendicular, and let fall upon *a*, then would *n* and *a* become ſtationary, and *c* be driven off to *o*, the diſtance *n* is from *a*. Fig. 3, Plate X.

5th. From the ſame elaſtic cauſe, if eight balls (or any other number) were hung ſo as to touch each other; if the two outſide balls were drawn off a little diſtance, and let fall upon the other ſix, the two balls only on the oppoſite ſide would be driven off, while the reſt would remain ſtationary; ſo equally is the action and reaction of the ſtationary balls divided amongſt them. Fig. 5, Plate X.

6th. If three of the above eight balls were drawn a little on one ſide, and let fall on the other five, the three outſide oppoſite balls would be driven off as far from the reſt as the three firſt fell, while the other five remained ſtationary. Fig. 4, Plate X.

SECTION II.

The Mechanic Powers.

COMPLEX as many machines may appear, they are only made up, more or leſs, of ſix mechanic powers, viz. the lever, the wheel and axle (or axle in peritrochio), pullies, inclined plane, the wedge, and the ſcrew.

A lever is a bar of any ſhape, long, ſhort, round, ſquare, flat, taper, &c. It is uſed to raiſe great weights a ſmall diſtance, and is of three kinds. The lever of the firſt kind has its fulcrum between the weight and the power, as *F*, fig. 6, Plate X.; the end of the lever *t s* being ſuppoſed a balance for the other part of it, *s r*. From *s* to *t* is called the acting part of the lever; and from *s* to *r* the reſiſting part of it: and it is as the acting is to the reſiſting part, that we gain an advantage over the body to be lifted; *i. e.* if the acting part *s t* be four times the length of *s r* (eſtimated from the fulcrum *s*), then will 1lb. hung at *t* balance 4lb. hung at *r*. Conſequently I could lift four times as much with this lever, as I could by main ſtrength. A ſcale beam is a lever of this kind: fig. 8, Plate X.: its centre *c* is the fulcrum, and the ſpot *n* its centre of gravity; and the nearer the centre of gravity and the fulcrum can be brought together, the nicer and more delicate will be the beam. Now, if two equal weights, *s* and *t*, be hung at equal diſtances from the fulcrum, they will balance each other, and the beam will be at reſt; becauſe the centre of gravity of the beam and weights is now at *o*, directly under the point of ſuſpenſion. But if *t* were removed to *a*, then the centre of gravity would not be under the point of ſuſpenſion *c*: and as it is a law of nature, that the centre of gravity always endeavours to fall or get beneath the centre of ſuſpenſion, or as low as it can, hence we ſee the reaſon why that end of the beam preponderates; and why a ſmall weight hung at *a* will balance the great weight *s*. On this obvious principle hangs the whole doctrine of mechanics; for we only ſubſtitute time or motion in the place of power, in all machines intended to aſſiſt animal ſtrength. For if I apply my weight at *a*, and can lift four times that weight at *s*, I ſhall deſcend at *a* four times the diſtance that the weight *s* will riſe. For if one man can raiſe by a machine as much as ten men could by main ſtrength, he will be ten times as long about it. If *s*, therefore, be 8lb., 2lb. at *a* will balance it, and the beam will be in equilibrio; for the momenta of the two arms, their weights, and motions, are exactly ſo. Suppoſe, then, that the weight *a* hangs twelve inches from the fulcrum *c*, and we call that its motion; this being multiplied by its weight, 2lb., gives twenty-four for the momentum of the arm *c a*. Now the weight *s* muſt hang three inches from the fulcrum *c* to balance *a*, for three times eight makes twenty-four, as well as two times twelve; ſo the two arms balance each other, like the Dr. and Cr. ſides of a merchant's ledger. On this principle depends the ſteel-yard, fig. 12, Plate X. where if *a* hangs ten times the diſtance from the fulcrum *c* that *b* does, then will *a* balance ten times its weight at *b*; and if put into motion, will move ten times as far. This lever may alſo be multiplied, ſo as to become infinitely powerful. Suppoſe at *a*, fig. 13, Plate X. there hangs 27lb., and that the acting part of this lever, *b c*, be three times the length of its reſiſting part, *b a*; in that caſe (agreeably to what has been proved), 9lb. of ſtrength applied at *c* will balance the 27lb. hanging at *a*, being one third of it. But to overcome the ſaid 9lb. I apply the lever *o d*, of the ſame acting and reſiſting powers as the laſt; ſo that 3lb. of ſtrength applied at *d*, will balance the 9lb. at *o*. But not ſatisfied with this, I apply another lever *r s*, whoſe acting is to its reſiſting part as three to one, as before, to overcome the 3lb., and reduce the power to 1lb. So that 1lb. hanging at *s*, will balance 27lb. hanging at *a*; and if put into motion, will move twenty-ſeven times as far: ſtill being only a ſubſtitution of time or diſtance in the place of actual power. The heavieſt waggons are weighed by compounded levers of a ſimilar principle. Handſpikes move the heavieſt guns; and the largeſt trees are torn up by the roots; as thus, fig. 1, Plate XI.—a ſtrong ſcantling is fixed on the ſtrong axle of the cart-wheels *c*; it is then tied to the tree at *r*; when the lateral roots of the tree are cut, by digging a trench round it, the tap roots are eaſily torn up by a team of two or three horſes; for the tree itſelf becomes the lever, and the axle of the wheels its fulcrum: the ſame wheels become a carriage for the tree to the place where it is to be tranſplanted.

Plyers, pincers, ſciſſars, hammers drawing nails, &c. are all levers of this kind.

The lever of the *ſecond kind* has its acting and reſiſting parts on the ſame ſide of the fulcrum, as *a b*, fig. 14, Plate X.: *a b* is the acting, *b c* the reſiſting part of this lever; and as the acting part is four times the length of the reſiſting, 1lb. hanging over a pulley at *a*, will balance 4lb. hanging at *c*.

This is the principle of a wheel-barrow: *b* may be conſidered as the wheel, which is the fulcrum, *c* as the load, *a* as the hands of the labourer. Hence the reaſon why a man can carry two, three, four, &c. times the weight in this machine, he can by main ſtrength.

A four-wheel carriage is a lever of this kind. If the centre of gravity of the load be half way between the fore and hind wheels, then will the acting part of the lever be twice the length of the reſiſting, as fig. 3, Plate XI. For when the wheel *a* comes to the obſtacle *c*, there will be but half the weight of the load to pull over it, becauſe the acting part of the lever *a b* is twice the length of the reſiſting part *b o:* it is true, that when the hind wheel *b* comes to the ſame obſtacle, the other half of the weight muſt be pulled over it; for then the acting part of the lever will be *b a*, the reſiſting *a o:* in the firſt caſe *b* was a fulcrum, in the ſecond, *a*. Though the ſum of theſe two reſiſtances is equal to what they would have been had the load been on one pair of wheels, yet by the four wheels the difficulty being divided into two parts, gives a leſs check to the draught of the horſes; and it is remarked, that nothing damps the ardour of that ſpirited animal ſo much, as ſudden jerks or checks in his draught.

A knife, moving from an hinge at one end, as *a*, fig. 2, Plate XI. is a lever of the ſecond kind: if from *a* to the handle *b* be four times as far as from the fulcrum *a* to the wood to be cut at *c*, then with ſuch a knife I could cut the wood with four times leſs exertion, than by a common knife of equal ſharpneſs.

The lever of the *third kind* has its acting part ſhorter than its reſiſting part, requiring more exertion than would be neceſſary to lift the body by main ſtrength; like rearing a ladder againſt a wall, or holding my cane (at one end) horizontally between my finger and thumb. Fig. 4, Plate XI. will explain it better; *a* is a weight to be lifted by the weight *b* pulling at *c*, over a pulley; *d* is the prop, or fulcrum. Now as the acting part of the lever, *d c*, is but one fifth of the reſiſting part, *d o*; therefore *b* muſt be five times as heavy as *a*, or it will not balance it.

Of this ſort of lever are the limbs of all animals. My arms, legs, fingers, are ſuch: the legs of quadrupeds, the wings of birds, and the fins of fiſhes.

The bone from my ſhoulder to my elbow is ſingle; that from my elbow to my wriſt double; (for the wiſe and uſeful purpoſe of turning in every direction). From the ſhoulder-blade *c*, fig. 10, Plate XI. there are two muſcles that terminate a little below the elbow at *e*; by the ſwelling of which (as at *d*), the arm or lever *n o* is enabled to lift the weight *s*. So that the bones *n o* are repreſented by the lever *d o*, in the laſt figure; the weight *s*, by the weight *a*; the elbow *n*, by the fulcrum *d*; and the muſcles *c d*, by the weight *b* pulling at *c*. Hence if the diſtance *n s* be ſix times the length of the acting part of the lever *n e*, and the weight *s* be 10lb., then muſt the contraction of the muſcles at *d* be equal to ſix times 10lb., or 60lb! Why has nature aſſembled ſuch a quantity of muſcles in the calf of my leg? Becauſe I was to lift my whole body, and walk by them. To puſh myſelf forward in walking, it was neceſſary that the reſiſting part of the lever, from my ancle to my toes, ſhould be much longer than the acting part, from my heel to my ancle, to have more ſcope on the ground; and that the contraction of the muſcles need not be too great. Accordingly, the foot, conſidered as a lever, has its acting part very ſhort, and put in motion by the *tendo Achillis*, a ſtrong fibrous tendon attached to the heel, and ending in many ramifications among the muſcles of the calf. It is a little mortifying to the pride of inveſtigation, to think that a reaſon cannot be given why we can bend one of our fingers: we talk learnedly of the living, or ſentient principle, of muſcular motion, and muſcular irritability; but we know nothing on this ſubject after all! We know that limbs are levers; the coupling of the bones, fulcra; that they are moved at will by a commanding muſcle or muſcles: but what is it that informs thoſe muſcles? There we ſtop. The philoſophy that has attempted to go farther, has hitherto been bewildered in obſcurity, conjecture, and jarring opinions: the mind has launched into an ocean, ſeemingly without bottom or ſide; perhaps, too wide and too deep for human faculties: for the few truths we ſeem qualified to attain, come beſt through the channel of the common ſenſes. What we can ſee, hear, feel, taſte, &c. we can reduce to experiment, obſervation, and compariſon; and from theſe form ſome probable conjectures, at leaſt, what is their deſign in the general order of nature.

The wheel and axle, or *axle in peritrochio*, is the next mechanic power; and may be conſidered only as a number of levers acting round one general fulcrum, or the gudgeon or centre on which the wheel is ſuſpended. A radius, or ſpoke of the wheel, being the acting part of the lever, and the radius, or ſemi-diameter of the axle, the reſiſting part of it. In fig. 5, Plate XI. *a b* is the wheel, *c e* the axle, *d* the gudgeon or centre. So that *a d* (the radius of the wheel) is the acting part of the lever; and *d e* (radius of the axle) the reſiſting part of it: hence if *a d* be twice the length of *d e*, then 1lb. hung at *a* will balance 2lb. hung at *e* (agreeably to the doctrine of the lever); and ſhews that wheels are to their axles as their diameters, and what is gained in power is loſt in time. This may be better underſtood by inſpecting fig. 6, Plate XI. where the axle in peritrochio is ſeen in profile.

Cranes for raiſing goods out of, or into, ſhips, warehouſes, &c. are principally of this mechanic power; capſtans, windlaſſes, &c. Cranes are of various conſtruction. The wharf crane is ſometimes moveable on a poſt fixed in the ground, as *a*, fig. 7, Plate XI. on which the machine and operator are both ſupported: a cogwheel, *c*, is fixed on the axle *o*, into whoſe teeth the pinion *d* works by the handle *b*. Now if the crank handle *b d* be five times the ſemi-diameter of the pinion *d*, then is the acting part of the lever five times the length of the reſiſting part; and I turn by this handle the wheel *c*, with one fifth of the ſtrength neceſſary to pull it round by its teeth. But the wheel *c* being twice the diameter of the axle *o*, this doubles the forementioned power; ſo that by theſe two powers I gain an advantage of ten; being able to raiſe ten times the weight I could by main ſtrength, allowing for the friction of the machine. The pulley *r* only changes the direction of the draught, but gives no mechanical power. So the whole turning on the poſt *a*, the package *s* can eaſily be turned from the wharf over the ſhip, and let down into it.

The *capſtan* has its power from the ſame principle: it is a long cylinder of wood, with holes in it for handſpikes, like *a*, fig. 9, Plate XI. The acting part of the lever is, therefore, from *c* to *d*, the reſiſting from *c* to *s*; (where the cable *n* is coiled round the capſtan). Now if a man's weight be applied at *d*, and *c d* be ten times the length of *c s*, then will the rope *n s* pull ten times his weight, allowing for friction, which in the capſtan is very great, as the centre on which it turns muſt be nearly as thick as the capſtan itſelf, when a ſhip is to be held at anchor by it.

The *large circular crane* in which a man or horſe walks, and which is actuated by his weight, is a cumbrous machine, and of trifling power. The man can ſeldom climb higher up the wheel than to *a*, fig. 11, Plate XI. ſo that the line *c o* is the acting part of the lever, and *d o* the reſiſting part: now if *c o* be only twice the length of *d o*, then can the man raiſe only double his weight; allowing alſo for friction, and the *vis inertiæ* of this unwieldy machine.

The *windlaſs* has its axle generally beneath the ſurface of the ground, as *a*, fig. 12, Plate XI. turning in ſtrong and fixed timbers: it is actuated by radiant handſpikes, as *s*, ſometimes by men and ſometimes by horſes, coiling up the rope or chain *q*. Now if each handſpike be ten times the length of the ſemi-diameter of the windlaſs, and there be eight handſpikes, then 10×8=80, which is the power of this machine.

SECTION III.

Pullies.

THE SINGLE PULLEY, unaccompanied by other powers, is not a mechanic power, for it gives no mechanical advantage: it ſerves to change the direction of a draught; and it gives a man an opportunity of applying his weight, inſtead of his muſcular ſtrength: but in this way he can lift no more than his weight; and without multiplication, no machine is ſaid to have mechanic power.

If two ſheaves be in the block *a*, fig. 13, Plate XI. and one in the block *b*, this aſſemblage will have a power of three, thus; faſten the rope to the lower block at *c*, and carry it over the nearer ſheave in the upper block, then under the ſheave in the lower block, and over the farther ſheave in the upper: the end of the rope being now held by the hand at *n*, it is evident the weight *w* will be ſuſtained by three ropes; and as all the ropes are equally ſtretched, of courſe each rope ſuſtains one third of the weight: now the hand *n* pulls but at one of the ropes, of courſe but at one-third of the weight; therefore the power of pullies, ſo ſyſtemized, *is as the number of ropes next to the weight,* and the hand *n* will fall three times as far as the weight *w* will riſe; ſhewing that what we gain in power we always loſe in time or motion.

The weight *w*, fig. 14, Plate XI. hangs by ſix ropes; and of courſe the power is ſix. But as the greateſt ſtreſs is on the ſheave *a*, over which the rope comes laſt (on account of the great friction in pullies), and as the centre of preſſure, as well as the centre of gravity, always endeavours to get under, or in a line with, the centre of ſuſpenſion, the ſtreſs on *a*, when the rope *c* is pulled, forces *a* under *b*, the centre of ſuſpenſion; making the ſheaves to rub ſo much againſt the block, as to make the friction nearly equal to all the power. This renders multiplication in pullies very limited; it is ſeldom that more than three or four ſheaves can be uſed with convenience. But the late ingenious Mr. Smeaton obviated this objection, by making the fall, or rope, *c*, to come over the middle ſheave inſtead of the outſide one: by this means the block is kept perpendicularly under *b*, and the ſheaves have no friction but on the centre on which they turn. This block, ſo uſeful for ſtretching the ſhrouds of ſhips, raiſing mill-ſtones, &c. may be eaſily underſtood by a mere inſpection of fig. 15, Plate XI.

It may be ſeen in this pulley, that it muſt always conſiſt of an *uneven* number of ſheaves, as three, five, &c.: this conſiſts of three large ſheaves, and three ſmaller, in each block; they are made ſo that the ropes need not rub on each other, and occaſion unneceſſary friction. To reeve this block, we faſten the end of the rope to the upper block, as at *a*; then carry it under the firſt large ſheave in the lower block; then over the firſt large ſheave to the right hand in the upper block; then over the firſt ſmall ſheave in the lower block to the right hand; then over the firſt ſmall ſheave in the upper block; then to the ſecond in the lower; then to the ſecond in the upper, and ſo through all the ſmaller ſheaves: then to the firſt large ſheave on the left hand in the lower block; then to the ſame in the upper block; then to the ſecond in the lower block; and then end at the middle large ſheave in the upper block.

The running block doubles whatever power went before it, thus: the weight *w*, fig. 8, Plate XI. is ſuſtained by the two ropes *a* and *b*; now if the rope *b* be faſtened to any thing, and *a* be pulled at, the pull need be but equal to half the weight, becauſe the rope *b* ſuſtains the other half: ſo *c* is called a running block. But a ſyſtem of running blocks may yet make the doctrine more evident. The weight *w*, fig. 16, Plate XI. is ſuſtained by the ropes *a* and *b*, each ſupporting one-half of the weight. Now if *b* be faſtened to the crane *d*, then to pull at *a* would be to lift only one-half the weight *w*. But we will apply another runner to ſuſtain *a*, by the two ropes *c* and *e*. Now if *e* be faſtened to the crane, then *c* ſuſtains half the weight of *a*, or one fourth of the original weight *w*. But ſuſpending the weight of *c* by the two ropes *o* and *n*, and tying *n* to the crane, then does *o* lift but half of *c*, or one eighth of the original weight. The uppermoſt pully only changes the direction of the rope, and adds nothing to the power. So that the loweſt runner doubled the power, the next doubled that, and the next doubled the laſt, &c. &c.

Hence if the weight *w*, fig. 8, Plate XI. be pulled at by the rope *a* with its other end fixed at *b*, the pulley *c* doubles the power, being a running block.

THE WEDGE. This power is applied to cleave wood or ſtone; to ſeparate heavy or cohering bodies: even the largeſt ſhips can be raiſed by an aſſemblage of wedges. The power of the wedge is *as its length is to the thickneſs of its back.* Let *a*, fig. 17, Plate XI. be the wedge, *c* and *n* two cylinders, hanging by their centres from the beam *d*, and pulled againſt the wedge by the weights *r* and *s* (repreſenting the reſiſtance to be overcome by the wedge). Now if *s* influence *c*, and *r* influence *n*, with each a force of 2lb. then 4lb. will be the difficulty to be overcome: and if the length of the wedge be *twice* the length of the thickneſs of its back, then will it be found that the wedge and it weight, *o*=2lb., will balance the 4lb. of reſiſtance; ſhewing that the ſtroke of a hammer = 2lb. would overcome 4lb.; or, that the power of the wedge is as the thickneſs of its back is to its length.

This is true, where cylinders or bodies with little friction are to be ſeparated: but where a blunt wedge is to penetrate a ſtone, or a piece of tough wood, a ton weight laid upon it would ſcarce force it in; when a ſmart ſtroke of a hammer, whoſe momentum was not a quarter ſo much, would do the buſineſs. So, whilſt I vainly endeavour with all my weight to force a nail into wood, the ſmalleſt tap with a hammer will do it effectually. Perhaps the ſmartneſs of the ſtroke may derange the coheſion of the body, and by making a quick vibration among the particles, diſpoſe them for ſeparation. But if it be conſidered that the momentum of a hammer has both the velocity with which it moves, and its weight multiplied together, and theſe concentrated into a momentary force, it appears ſtrange that its effects ſhould be conſidered as a myſtery.

THE INCLINED PLANE is, in reality, but a ſtationary wedge; by it we eſtimate the power neceſſary to drag carriages up-hill, the deſcending force of rivers, &c.; and its power (like the wedge) is *as its length to its height.* Let *a c*, fig. 18, Plate XI. be an inclined plane, riſing one foot in three; or whoſe length, *a c*, is three times its height, *a d*. Now, if a cylinder or roller *n* be 3lb. weight, 1lb. *o*, hanging over the pulley *r*, will be found to balance it; or, I ſhould drag the weight *n* with three times leſs exertion up *a c*, than I could lift it perpendicularly from *d* to *a*; but in this caſe, I move it three times as far: ſhewing, both in the wedge and inclined plane, that we only ſubſtitute time in place of power. This is the reaſon why roads ſhould wind zig-zag up ſteep hills, to flatten the declivity, though it increaſes the length. The draught of a carriage of any weight, and on any kind of road, may be eſtimated by means of the inclined plane, thus: provide a board or box, *a b*, fig. 24, Plate XI. capable of holding pebbles, mud, ſand, &c. and which can be raiſed at one end by the ſcrew *d*. When *a b* lies flat on *c b*, the carriage *n* will be at reſt; the ſcrew now raiſing *a b* leiſurely, the carriage will, at a certain height, ſet off of itſelf, and roll down the plane. Here then are we in poſſeſſion of a triangle, that ſolves what force is neceſſary to drag any load, on any kind of road, on level ground; for the hypothenuſe *a b* repreſents the weight of the carriage, and the perpendicular *a c* what portion of that weight is neceſſary to draw the carriage on level ground. Suppoſe the carriage 12cwt.; the line $a\ b = 24$, and the height $a\ c = 3$: the declivity then is as 3 to 24, or as 1 to 8. In this caſe it will be found, that one eighth of the weight of the carriage would drag it in ſuch a road on level ground, viz. 1½cwt. But if the road was very deep or rough, the road might be raiſed, perhaps, as high as *s*, before the carriage would ſet off. Now if *c s* were half the length of *s b*, then would it require one-half the weight of the carriage to drag it on level ground, or in the above caſe 6 cwt. This rule is univerſal, and has been proved by carriages at large, on roads of every deſcription. In eſtimating the draught up hill, the draught on the level muſt be added to it. Suppoſe the hill riſes one foot in four; then one fourth part of the weight muſt be added to the draught on level ground. If the weight (as before) be 12 cwt. then one fourth of it would be 3 cwt. and its draught on the level was $1\frac{1}{2}$ cwt. theſe two make $4\frac{1}{2}$ cwt. the real draught neceſſary to draw 12 cwt. up a hill riſing one foot in four, &c.

THE SCREW is but an inclined plane, wrapt as it were round a cylinder, as *a*, fig. 20, Plate XI.; its power, therefore, is *as the length of its thread to its height*; or as the hypothenuſe *c d* is to the perpendicular *c e*; or as the circumference of one thread is to the diſtance of the threads from one another. May not the lever, the wheel and axle, and the pullies, be all conſidered as only modifications of the lever? and, for the ſame reaſon, the wedge, inclined plane, and the ſcrew, but as modifications of the wedge? May not, therefore, the ſcrew, influenced by the lever, be conſidered as the quinteſſence of all mechanic power; and that there is, in reality, but two mechanic powers inſtead of ſix?

SECTION V.

On Friction.

FROM theſe calculations, however, conſiderable deductions muſt be made, for unavoidable friction, and the imperfect manner in which machines are generally made. Friction is ſaid to be of two kinds, the rubbing friction, and the friction by contact: the firſt may be repreſented by a locked coach-wheel dragging on the road; the ſecond by the wheel touching the ground in its uſual motion. If the axles of wheels, the gudgeons of mills, and other parts that rub, be poliſhed as well at poſſible, there will ſtill be in them little eminences and little hollows, which, locking into one another, produce the impediment called friction of the firſt kind; *this* is, perhaps, the leaſt when well poliſhed iron and bell-metal rub on each other. Friction-wheels, however, do little good, except in machines whoſe rapid motion would ſet them on fire: in heavy machines they wear into notches, and are too liable to be out of order, to be uſeful. But the enormous ſtone in the grand ſquare of Peterſburgh was moved on ſteel balls, fig. 25, Plate XI. Bridges over canals frequently can be turned out of the way of boats by moving on friction-balls, fig. 22, Plate XI. So the heads and ſails of windmills, the domes of obſervatories, &c. can be eaſily turned on frames of friction-rollers; as well as the ſheaves of common pullies, mangles, &c. Fig. 26, Plate XI. though ſtraight, may repreſent a part of the round bottom of a dome; *a b* the wall plate; *c d* bottom of the dome; *e n* the frame going round the dome, containing the friction-rollers at proper diſtances from each other; on which a heavy millhead, or dome, may be turned round by the hand. So in the pulley, fig 19, Plate XI. if the axle *a* be touched only by the friction-rollers (kept in a circular frame at a proper diſtance from each other), and the pulley *p* turn on their outſide, three men are ſaid to lift by this pulley as much as five with the uſual one. The moſt uſual mode of uſing friction-wheels is as in fig. 21, Plate XI. where the wheels *a* and *b* form a notch for the axle *c* to turn in; *a* and *b* do not touch, but are very near one another, and turn on ſmall pivots almoſt without friction. Two ſimilar wheels being on the other ſide of the large wheel *N*, ſupport the other end of the axle *c*. Theſe are the uſual applications for diminiſhing friction; and where it is not diminiſhed by ſome of theſe methods, we generally, in machines conſiſting of three or more powers, allow *one third* for rubbing, and imperfection.

A common crane will ſerve for an example, fig. 23, Plate XI. We begin the calculation firſt with the crank-handle *a*, which is five times as far from the centre of the pinion *b*, as the teeth of the pinion; according to the principles of the lever, I gain five by this handle: the next power is the wheel and axle; the wheel *W* is made purpoſely to be twenty times the diameter of its axle *c* (round which the rope of the crane is coiled); by this power I gain an advantage of twenty: ſo five times 20 is 100, the power of the crank-handle and the wheel and axle together. Tracing the power along the rope *d*, it paſſes over the pulley *e*, which changes its direction, but gives no power. We then come to the weight *P*, which hangs by ſix ropes, but the axle *c* is pulling but at one of them; ſo this aſſemblage of pullies multiplies the former advantages ſix times; then ſix times 100 is 600, the *theoretical* power of the whole machine: and I ſhould go with my hand (at *a*) 600 times as far as the package *P* would riſe. But, by trial, I ſoon find I cannot raiſe 600 times as much as by main ſtrength: the rubbing of the axles of the wheel and pinion, the contact of their teeth, the coiling of the rope, and the allowance for pullies, is one-half for friction; altogether, one third muſt be allowed for friction, and the imperfect manner in which machines are commonly made; ſo that inſtead of ſaying, according to theoretical calculation, I can by this machine lift 600 times as much as I could by main ſtrength, I can in reality lift but two thirds of it, or 400 times as much.

This crane is made in a variety of ways, both for convenience and force; and has generally the projecting part *x* to turn on a ſtrong hinge at *e*, for the convenience of landing, ſhipping, or houſing of goods.

Informed of our power, we can, by theſe means, eaſily calculate what that power can produce. A middle-ſized horſe can draw for eight hours in a day, with a conſtant force, equal to 32 lb. What load can he draw upon a plain road as a momentary exertion? Suppoſe the declivity before the carriage ſets off of itſelf to be one inch in 32 (ſee page 104), then 32 lb. multiplied by 32, the declivity, is 1124, or ſomething more than 10 cwt. for a few minutes.

2d. A plough requires, in common land, 80 lb. to draw it; hence two, and generally three, horſes are yoked to it.

3d. I have a brook, with a ſufficient fall, in my eſtate, that with penning will afford me 300 lb. of water to act upon a wheel; but a millſtone requires 600 lb. force to carry it ſixty times round in a minute (its proper velocity). I muſt in that caſe make the cog-wheel (which overcomes the reſiſtance) but half the diameter of the water-wheel: by this means I make 300lb. of power overcome 600lb. of difficulty.

4th. I want to raiſe a hundred weight of water out of a well, at one draught: the horſe draws, in common, little more than 30lb. and that is contained nearly four times in 112lb.; ſo the wheel round which the horſe's rope is coiled muſt be nearly four times the diameter of the axle round which the bucket rope is coiled, and the horſe will draw it up with eaſe, walking ſtraight forward.

5th. I want to drive piles into the ground, that require a ram of 15cwt.; what number of men muſt I hire to work it? A working man weighs, at an average, about 1½cwt.; ſo that ten men muſt be hired, to draw it up about ſix feet, and then ſuddenly to let it fall on the head of the pile.

6th. I want to raiſe a ſtone to the top of a building of 200lb. weight, the rope to go over a pulley hung at the end of a projecting beam above the top, and to go under a pulley fixed in the ground; what number of horſes will this require? In the firſt place, theſe pullies give me no mechanic power; but rather add to the difficulty by their friction. If then a horſe's power is 32lb. there is ſix times 32 in 200, ſo that ſix horſes will be required. But for a ſudden and ſhort exertion a horſe will exert ſeveral times the power he does in ordinary draught; upon ſuch an emergency, therefore, three or four horſes would do it.

From ſuch conſiderations as theſe do we calculate the ſize of wheels, the length of levers, &c. for every mechanic purpoſe.

SECTION VI.

On the Wind-mill.

THIS machine is capable of being turned ſo as to face any wind, by having its top or dome ſuſtained on ſuch friction-rollers as are deſcribed page 106. The eaſe, therefore, with which the ſails, the axle, and cog-wheel, contained in the dome *a*, fig. 2, Plate XII. can be turned to the wind, depends on theſe, and the multiplying powers of the fly-wheel *e*. This wheel conſiſts of a number of triangular thin boards, each forming an angle of 45° with the plane of the wheel. On the axle of this wheel is a thread, or ſcrew, which fits into the teeth of the wheel *o*, and gives motion to it; this wheel turns on an axle, whoſe pivot is in the ſupport, denoted by the ſpotted lines, and its other end is in a ſocket faſtened in the dome: on this axle is the pinion *z*, which turns in a fixed contrate wheel, on the wall plate of the mill. When the wind changes from the principal ſails, it inſtantly puts the fly-wheel *e* into motion; this turns the wheel *o*, whoſe pinion *z*, not being able to turn the fixt wheel on the wall, is turned itſelf, and with it, the ſails, the dome, and all that it contains: this effect continues till the fly-wheel gets into the lee of the dome; it then ceaſes, and the ſails being brought to face the wind, are put into motion. Hence ſuch a mill always turns itſelf to the wind, preventing the care of ſervants. The great ſails produce an equal motion in an high or low wind, by being clothed with half-inch boards inſtead of canvas: theſe little doors are puſhed open by a ſtrong gale, and they ſhut when the wind is weak; ſo that by playing with the momentary inequalities of the wind, a quantity of ſurface is always preſented in proportion to the impulſes of it. A pin is ſtuck into the corner of each door, as at *w*, and all the pins are united to a cord, which paſſing over the pullies *u*, is faſtened to a wire, *x*, going through the axle *m*: on the other end of this wire is a nut, turning in the reſiſting part of the crooked lever *s*; ſo that the motion of the ſails does not interrupt the operation of the weight *k*, which can be made more or leſs, according to the ſpeed the mill ſhould go at. That the wind may have its full effect upon the ſails, one ſail ſhould not ſucceed into the place of another before the wind has reſumed its regular current; for, acting upon inclined planes, it is interrupted, and obliged to puſh by, and give an impulſe to every ſail in its paſſage: hence it is found that five ſails are a *maximum*; i. e. they are better than four, and better than ſix. Wind has the greateſt effect upon inclined planes, that form an angle of 45° with its direction; but as this inclination offers ſo great a ſurface of reſiſtance to the rotatory motion of the ſails, it is found that 30° near the axle degenerating gradually to 5° towards the end of the ſails, is beſt. A mill of this conſtruction, with each arm or ſail ſeven feet long, is equal to the ſtrength of a man.

Horizontal wind-mills are weak in compariſon of thoſe whoſe arms are inclined planes; for, by giving way, or falling back from the impulſe of the wind, like a ſhip, the power is not half what it is againſt a plane that ſtands firm againſt the wind But the advantage of going round always the ſame way, with every wind, without attendance, may, in ſome caſes, be thought adequate to the want of power, the vaſt expence of building, and the unſightly tower it exhibits when built.

The reaping machine is actuated by a horſe, and may be uſeful when corn is full ripe, and hands cannot be procured to reap it. Fig. 5, Plate XII. is a ground-plan of the machine; and fig. 3, its elevation. The bottom plate, *a*, is of ſtrong ſheet-iron, to which is welded or rivetted the ſteel points *c c c*, each of which has a ſharp edge on the ſides *x x*. The wheel *s s* is of iron, and has ſeven knives fixed upon it, their cutting edges at *g g*. This wheel, with its knives, is put in circular motion by the pulley *n* fixed on its axle, between the two plates *a* and *d* (ſee the elevation). This pulley has motion given to it by the cord *m m*, which goes round the wheel *z z*: and the wheel *z* has a pinion, *i i*, on its axle, whoſe teeth conform to the cogs of the perpendicular wheel *q q*. The wheel *q q* is on the axle of the two cart-wheels *k k*, and theſe are put into motion by the horſe, which puſhes the machine forward at his breaſt, as in mills that are actuated by horſes. The ſteel points *c c* are puſhed into the corn, and ſerve not only to hold it faſt while cutting, but their ſharp edges *x x* become half a pair of ſhears or ſciſſars, and the circulating knives the other, by which the corn is cut, and falling on the platform *s*, is ſwept by the rod *u* (fixt on the axle of the wheel *n*) off the platform, and laid out of the way of the cart-wheel, ſo as to be eaſily bound up into ſheaves. But when the machine returns, the lever *u* would throw the cut corn among the ſtanding corn; it muſt, therefore, be taken out of its ſocket, and the rod *w* put in its place, the point of which, *o*, ſtands perpendicularly, and catches every revolution a lever or rod turning on the fulcrum *p*, and ſweeps off the cut corn, laying it like a ſwath on the ſide already cut. This lever ought to have a ſpring to bring it back, when diſengaged from the pin *o*, and a joint or hinge to prevent its ſweeping the cut corn the wrong way. The ſingle wheel *r* is to ſupport the fore-part of the machine, and may be fixed higher or lower, ſo as to make the ſtubble ſhort or long. A ſemi-collar is made to fit the horſe's breaſt, and ſo fixt, that he may be eaſily diſengaged: a boy may turn and manage the machine.

The drawings of this machine are on a ſcale of an inch to a foot. A horſe will cut a ſwath two feet wide, as faſt as he can walk; or rather more than could be reaped in the ſame time, and in the uſual way, by ſix men.

The thraſhing machine, fig. 1, Plate XII. is made to ſtrike the corn and ſtraw both before and behind, and more effectually to beat out the grain than when ſtruck in the uſual manner, all one way. A man ſpreads out the ſheaf on the ſmooth inclined plane *a*, againſt which the rough roller *c* draws in the ſheaf, and holds it ſo faſt while it draws it through, that the ſwinging flails (ſtriking it in a contrary direction) may beat out all the corn in its paſſage. The flails *g* hang by hinges on the axles of the two wheels *x* and *n*, which are put into motion by the firſt mover, the large wheel *w*. The grain and ſtraw fall on the grating *F*, the grain falling through, while the ſtraw is toſſed off This machine may be worked by wind or water, man or beaſt.

SECTION VII.

The travelling Corn-mill. Fig. 10, *Plate XIII.*

THIS mill depends on the draught of a horſe and the friction of the road for its motion. It is meant to move round a green, or any ſmooth road, and to travel from one houſe or village to another. *a b* is a ſquare frame of ſcantling, fixed on the ſhafts of a common cart: in this frame is fixed the caſe *c*, which contains the iron mill-ſtones *d*; the upper ſtone, as uſual, turned and ſupported by the trundle or pinion *e* (the ſupport of which, and its regulator, cannot be repreſented in the drawing, but are the ſame as in a common mill). The iron part of the ſpindle that is fixed into the ſtone is ſupported on three or four friction-wheels, to keep the ſtone ſteady when any inequalities are in the road; and which can, by ſcrews, raiſe or depreſs the ſtone according to the fineneſs of the flour required, or the grain to be ground. A circular ſyſtem of friction-rollers, like fig. 19, or 26, Plate XI. would ſtill do better. A cog-wheel, *A*, is fixed on a ſquare part of the axle of the cart-wheels, and is about a foot leſs in diameter. This cog-wheel can be eaſily ſeparated from the trundle *e*, when the mill travels from one place to another. Inclining under the ſtones is the bolting-ſieve *z z*, repreſented by ſpotted lines, with teeth that act in the trundle *e*. The flour is ejected from the ſtones into this circulating ſieve, and falls through it into a cloſe caſe that depoſits it in the bag *o*; while the bran flowing through the length of the ſieve, is received in another bag. The ſtones ſhould be about three feet in diameter (if of caſt-iron, ſo much the better), and the whole machine covered. It is conceived, one horſe will draw the mill and a miller, and grind a buſhel of wheat in travelling about one mile and an half.

EXPERIMENTS

TO ASCERTAIN THE EXCELLENCES AND DEFECTS OF

WHEEL CARRIAGES:

From whence Deductions are made for the Improvement of Coaches, Carts, Waggons, &c.

SECTION VIII.

IN a country where mechanics have made ſuch a progreſs, where almoſt every operation for either uſe, convenience, or pleaſure, ſeems nearly to have reached its ultimatum, it is wonderful that ſo little improvement has taken place in the mechanical part of our wheel carriages: in the ornamental part, I grant, art and ingenuity have gone ſo far towards perfection, that all nations do homage to this, by having their more elegant carriages made here. Had there been the ſame attention paid to their mechanical conſtruction, and to the eaſe of the much-abuſed animals that draw them, the following experiments had not been made. I ſhall, therefore, take upon me to plead the cauſe of that firſt of quadrupeds, a horſe; and if I am happy enough to excite any efforts in favour of his eaſe or comfort, I ſhall eſteem it more than a reward for what I have done with an intention to ſerve him.

Before we enter upon the difficulties which wheel carriages have to ſurmount, it will be neceſſary to examine the formation of the animal by which theſe machines are put in motion. A horſe, conſidered as a machine, is admirably conſtructed for motion, draught, or ſuſtaining weight. His limbs, conſidered as an aſſemblage of levers, would require a volume to point out the wonders in their contrivance, and that of the muſcles by which they are actuated: but the formation of his ſhoulders is the ſubject to which I wiſh to direct the reader's attention.

It is evident, that at the place where the neck riſes from the cheſt of the horſe, the ſhoulder-blades form the reſting-place of his collar, or harneſs, into a *ſlope* or *inclination*; and as this ſlope or inclination forms an angle, with a perpendicular to the horizon, of about 14 or 15 degrees, it is evident, the line of his draught ſhould form the ſame angle with the horizon, becauſe he will then pull perpendicularly to the ſlope of his ſhoulder, and all parts of that ſhoulder will be equally preſſed by the collar. Fig. 1, Plate XIII. may render this more intelligible, and ſhow that a horſe draws more conformably to his mechaniſm in a ſloping, than an horizontal line.

But the advantage he has in overcoming obſtacles to his draught, by this inclined direction, is alſo *mechanically* great, as may be demonſtrated by fig. 4, Plate XIII. Call *A* a wheel, *b* an obſtacle, *c* the axle of the wheel, *d* the ſpoke which at preſent ſuſtains the weight. A line drawn from the neareſt part of the horizontal line of draught *c k*, to the fulcrum or obſtacle at *e*, will form the acting part of a lever * *g e*; and another line *e d* being drawn from

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* What is here meant by the acting part of a lever is its longer arm, the reſiſting part is the ſhorter arm.

the fulcrum *e* to the neareſt part of the ſpoke *d*, will form the reſiſting part of the ſame lever. Now as the acting and reſiſting parts of the lever are of equal lengths (i. e. are ſines of equal arcs), the lever becomes a ſcale-beam, and a draught in the line *g k* muſt be equal to the weight of the wheel, and all that it ſuſtains, beſides the friction. For if *g e d* be a crooked lever, a pull at *g* muſt be equal to all the weight ſupported by *d*. Now when a horſe draws agreeably to the ſhape of his ſhoulder in the line *i h*, the acting part of the lever *h e* is lengthened nearly one fourth; ſo that if it would require a pull at *g* equal to four hundred weight, a power applied at *h* will draw the wheel over the obſtacle *b* with *three hundred weight*. To thoſe unacquainted with the principles of mechanics, this truth may be eaſily proved by an ordinary ſcale-beam. The horſe himſelf, conſidered as a lever, has in this inclined draught a manifeſt advantage over his obſtacles, in compariſon of an horizontal draught, as may be ſeen by fig. 2, Plate XIII. When the horſe is yoked to a poſt, or has any great obſtacle to overcome, he converts himſelf into a lever, making his hind feet the fulcrum, and the centre of gravity of his body to lean over it at as great a diſtance as poſſible, by thruſting out his hind feet; by this means acting both by his weight and muſcular ſtrength, and lengthening the acting part of the lever *a b*, he overcomes the difficulty more by his *weight* than by his muſcular ſtrength: for the muſcles of the fore legs act upon the bones to ſo great a mechanical diſadvantage, that though he exerts them with all his might, they ſerve, in great difficulties, for little more than props to the fore-part of his body. Hence we ſee the great uſe of heavy horſes for draught. But the great mechanical uſe and advantage of the inclined line of draught may be more particularly ſeen, by calling the line *a b* the acting part of a lever, and the neareſt approach from the fulcrum *b* to the inclined line of draught (that is, *b c*) the reſiſting part of the lever; compare this with the reſiſting part of a lever touching the horizontal line of draught (that is, *b d*), and it will be found nearly double; conſequently, agreeable to the known properties of the lever, a weight at *g* would require double the exertion in horſes to remove it, that the ſame weight would require was it placed at *e*. Theſe advantages, great as they are, are yet ſo obvious, that one wonders how they could be overlooked. Let any one with the model of a horſe from a toy-ſhop, ſet his hind feet on the edge of a table, fig. 5, Plate XIII. and it will be found that he will draw double the weight along the table *a*, that he can upon the table *b*.

The obvious concluſion from the experiments is, that ſingle-horſe carts are preferable to teams:—that four horſes, with each a properly conſtructed cart, will draw more, and with more eaſe to themſelves, than when they are yoked in a team to one cart; becauſe, in that caſe, three of the horſes muſt draw horizontally, and conſequently in a manner inconſiſtent with their mechaniſm, and the eternal laws of mechanics. Practice alſo proves the truth of this theory. The ſmall horſes of the north of England draw more weight of actual goods than our largeſt waggon horſes, and go longer ſtages. The ſmall horſes of Ireland draw, as a common load, 15 cwt. of goods, and travel farther per day than our waggons, and over worſe roads than ours are in general: whereas 10 or 12 cwt. is as much as falls to the ſhare of one waggon horſe of real goods, his ſuperior ſtrength being waſted upon a cumberous and ill-contrived vehicle.

Waggon wheels are generally formed as fig. 3, Plate XIII. I ſuppoſe the reaſon why the wheels are made to run on an inclined axle, is to make the body of the carriage more roomy; and that each ſpoke when its turn is to ſuſtain the weight, may ſtand perpendicular under it. But what are the ſacrifices that muſt be made to theſe conveniences! In the firſt place, the machine muſt ſtand on a narrow baſe, and be thence very liable to be overturned; the inclined axle muſt be enormouſly ſtrong to reſiſt the laternal preſſure of ruts and ſide pavements; and, worſt of all, the wheels, being of a different circumference on their two ſides, the ſmaller circumference muſt be reduced to the ſtate of a ſledge every time it goes round, in the proportion as it is leſs than the other; that is to ſay, if the circumference *c d* in the foregoing ſection be 10 inches leſs round than the circumference *a b*, then will 10 inches of that ſide of the wheel be dragged on the road like a locked wheel every time it goes round! What an additional and unneceſſary draught muſt this be to the poor horſes! and what an injury to the roads!—A broad wheel is thus rendered a mill-ſtone, and grinds to powder the hardeſt flint gravel! In vain may our legiſlators make laws to preſerve the roads by broad wheels, ſo long as this abſurd practice is ſuffered. I venture to affirm, that more real miſchief is done to the roads by *ſuch* broad wheels, than would be done by narrow ones! I have heard the late Sir George Saville ſay (and he was the beſt gentleman mechanic, both theoretical and practical, I ever knew), that he had calculated how far a waggon was rendered a ſledge in a journey to York from London. The diſtance is 200 miles, 30 of which the waggon is drawn as a ſledge without wheels!—What a tax is this upon horſes! what a tax upon the roads! Some waggoners have found the art of making the tire of their wheels protuberant, or bulging in the middle, by which they touch a hard road with little more ſurface than a narrow wheel; thereby doing the ſame miſchief as narrow wheels, and evading the tax upon them.

But of what a weight and ſtrength muſt ſuch wheels be made, to ſupport the enormous loads laid upon them! Both of which in waggons muſt add exceedingly to the draught of the horſes, becauſe a waggon, from the ſlowneſs of its motion, obliges the horſes to overcome it *vis inertiæ* every moment they are drawing it. That is, it is the ſame thing as putting it into a ſtate of motion from a ſtate of reſt every moment: for every one knows how ſmall a force is capable of keeping a heavy body in motion, when it is once in motion, to what is neceſſary to put it in motion from a ſtate of reſt. But what that difference is, will be more particularly conſidered hereafter. At preſent, I confine myſelf to the particular oppreſſion of horſes, and the damage done the roads, by the preſent mode of carrying goods from one place to another. If the aforeſaid doctrine be true, viz. that a horſe was deſigned by nature to draw in a ſloping or inclined direction, then ſix out of the eight horſes in every team muſt draw inconveniently, and inconſiſtently with their mechaniſm, for they *muſt* draw horizontally; ſo that much exertion is miſapplied: the horſe's collar is alſo drawn againſt his throat, by which his breathing is interrupted: and in cart teams (where the horſes are not marſhelled, as in waggons), one horſe is ſtanding ſtill, perhaps, while another is waſting his ſtrength in pulling him forward. One horſe, to eaſe himſelf, leans one way out of the line of draught, whilſt another is leaning a contrary way: in ſhort, their ſtrength is ſeldom united. I do, therefore, believe, that ſix horſes yoked to ſix ſingle carts, would draw more, with more eaſe to themſelves, than when ſix are yoked in one team. But as an act of parliament ſays, that one man at leaſt muſt accompany every team, is it not cheaper to pay for ſix horſes, than to pay for ſix men? Certainly. But I venture to declare the ſix men unneceſſary; for it is no uncommon thing to ſee ſix or eight northern ſingle carts driven by one man: he ties the halter of one horſe to the cart which goes before it, and by this means has the whole as much at command as if they were yoked in the chains of a waggon. A horſe has alſo the momentum of his draught increaſed by having a portion of the weight on his back. We may alſo ſee that there is not ſo great a diſadvantage in the draught of low wheels as is generally imagined; for low wheels oblige the line of draught to incline, agreeably to the natural draught of the horſe, which is more than an equivalent for the diſadvantage a low wheel has, conſidered as a lever. Wheels drawn horizontally, do not increaſe in their mechanic power, in the proportion of their height. If a wheel be three feet ſix inches in height, and drawn from any part of the carriage, ſo that the line of draught continued might paſs three inches below the centre of the axle, it would have all the advantages of a wheel of four, five, or ſix feet in diameter or height: for the lift in a ſloping draught gives the ſame advantage to a ſmall wheel, that a larger wheel would have from its mechanic power, without the incumbrance of its weight.

There is a maximum, however, in the height or diameter of wheels, beyond, or ſhort of which, we cannot go without an outrage on mechanic propriety. In uneven countries, if wheels are above ſix feet in diameter, they muſt be made ſo ſtrong, that their weight will more than counterbalance their mechanic advantage: if they are leſs than three feet, they are not fit for a ſoft country:—we are here ſpeaking of two-wheeled carriages. In four-wheeled carriages we are obliged to have low fore-wheels for the convenience of turning, not becauſe there is any puſhing quality in tall hind-wheels, according to the ideas of John the Waggoner, or of my Lord Jehu, who both place themſelves and their luggage on the fore-wheels of their reſpective carriages, no doubt for the wiſe purpoſe of being puſhed forward by the hind ones! In my lord's phaeton the hind-wheels ſtalk behind, ſomething like a tall footman following his diminutive lady, having nothing to carry but her lap-dog! Poor John has ſome excuſe for laying the centre of gravity of his load upon the fore-wheels, becauſe he muſt leave the tail of his waggon open, to receive goods by the way, as he goes along. But that, in a phaeton, it ſhould ever enter into the mind of man, that two riders, placed in a dangerous and ridiculouſly-elevated ſeat, with the apparatus neceſſary to ſupport ſuch a birds'-neſt, together with a heavy boot, ſhould be all loaded on thoſe wheels the leaſt capable of getting over obſtacles, and leaving the tall hind-wheels nothing to ſupport, is a paradox in human reaſoning above my capacity to ſolve. Perhaps it may be matter of pride to ride on horſeback without touching the horſe; and, perhaps, well worth hazarding a neck to be ſo far elevated above our fellow-creatures. But let pride and folly enjoy their diſtinctions: it is the office of ſcience to cultivate the uſeful.

SECTION IX.

Containing Experiments on Coaches, Chariots, Curricles, &c. &c.

TO prove that a horſe ſhould have ſomething to lift in his draught, to give that draught its utmoſt momentum, the following experiments were inſtituted:

With a well-executed model of a four-wheeled carriage, whoſe weight was 82 ounces; the fore-wheels $8\frac{1}{4}$ inches, as fig. 6, and the hind-wheels 10 inches; drawn on an horizontal board by a line over a pulley: an obſtacle $1\frac{1}{2}$ inch high was placed before the fore-wheels, and the *ſplinter-bar* raiſed on the *futchels*, ſo as to be even with the top of the fore-wheel, as at *a*, fig. 6, Plate XIII. The line of draught was then horizontal, as *a b*.

	Ounces.
Things being ſo diſpoſed, the weight neceſſary to draw the fore-wheels over the obſtacle was . . .	42
2d. Every thing the ſame as in the laſt experiment, only the ſplinter-bar lowered to *b*, ſo as to make the line of draught to be from three fourths the height or diameter of the wheel. Weight required was . . . . , ...	30
3d. All as before, only the ſplinter-bar ſo lowered, to *c*, as to make the line of draught from the axle .	24
4th. Every thing as before, only the point of draught made from a ſplinter-bar one inch below the axle of the fore-wheel, as *d*. Weight	$22\frac{1}{2}$

Hence may be ſeen that the diſadvantages of drawing from *above* the centre are as the ſines of the reſpective arcs paſſing through the ſplinter-bar; and the advantages of drawing from *below* the centre, alſo as the ſines of the reſpective arcs. Now as the ſplinter-bar, or point of draught, in moſt of our carriages (nay, I believe, I may ſay all), is placed about one fourth the diameter of the fore-wheel above its centre, it is evident that a fortuitous preſſure, equal to one fifth of whatever weight lies upon it, is actually added to the natural weight, by this unnatural ſituation of the point of draught! For, by the above ſcheme, it may be ſeen that twenty-four ounces of draught ſurmounted the obſtacle, when the pull was from the centre; and that it required thirty ounces to ſurmount it, at half the length of a ſpoke *above the centre*.

Another courſe of experiments was made at my houſe, before ſeveral gentlemen well verſed in mechanics, on a waggon-like model, weighing about 156 lb.; the fore-wheels four feet two inches in diameter, and the hind-wheels five feet ſix inches; with an obſtruction placed againſt the two fore-wheels of 6¼ inches.

	Pounds.
1ſt. The line of draught was perfectly horizontal, or even with the top of the fore-wheels; in this caſe, to draw it over the obſtruction required . . .	60
2d. When the direction of the line of draught made an angle with the horizon of ſeven degrees, by lowering the point of draught ſix inches below the top of the wheel, it required	48
3d. When the end of the line of draught was lowered, till the direction of it was at an angle of 11° with the horizon, it ſurmounted the obſtruction with	41

		Pounds.
4th.	When the end was lowered to the centre of the wheel, and the line of draught was at an angle of 15° with the horizon, the obſtacle was ſurmounted with	$33\frac{1}{2}$
5th.	When the end of the line of draught was lowered to $6\frac{1}{4}$ inches below the centre or axle, ſo that the angle with the horizon was 17°, it was drawn over with	$30\frac{1}{2}$
6th.	When it was lowered to one foot and half an inch below the centre of the wheel, ſo that the angle was 18°, it was drawn over with	29
7th.	When it was lowered to $18\frac{3}{4}$ inches below the centre (being only $6\frac{1}{4}$ inches above the road, and exactly level with the height of the obſtruction), the angle 23°, the weight neceſſary to draw it over the obſtruction was	27

Theſe experiments, though made upon ſo much larger a ſcale than the former, produce a ſimilar reſult; ſo that there is no reaſon for the too general, and often falſe, opinion, that what may ſucceed in model, or miniature, will not ſucceed at large.

An experiment with a common chaiſe, when drawn by a ſplinter-bar as high as the top of the fore-wheels, proved that it required 80 lb. to put it in motion. When drawn from the axle, it required only 51 lb.

With another chaiſe, and the ſplinter-bar three fourths of the height of the fore-wheel, the draught over an inch obſtruction required 100lb. But when drawn from the axle, only 61lb.

With another chaiſe, and the ſplinter-bar three fourths of the height of the fore-wheel, the draught over an inch obſtacle required 119lb. But when drawn from the axle, only 93lb. So that in both caſes there was one fourth in favour of the draught from the axle.

With the ſame chaiſe, drawn up a hill, riſing one foot in ſix, with the ſplinter-bar one fourth of the wheel's diameter from the top, it required 168lb. to draw it up. But when drawn up the ſame hill from the axle, it only required 129lb.; there was therefore the ſame advantage nearly in this mode of draught up-hill as on level ground.

The ſame experiments with larger wheels made the advantage ſtill greater.

Another experiment with a light coach, on level planks, was to draw it by an horizontal line from the ſplinter-bar; the carriage required 143lb. to put it into motion: when drawn horizontally from the axle, it required only 85lb. to put it into motion.

N.B. When ropes are faſtened to the tops of the fore-wheels, the weights hung to them were but half of the above 85lb.; for, by this mode of draught, the perpendicular diameter of the wheel becomes a lever of the ſecond kind, the ground the fulcrum, the diameter the acting part of the lever, and the ſemi-diameter the reſiſting part of the lever.

SECTION X.

Contains Experiments to aſcertain the beſt Proportion between the Heights of the fore and hind Wheels, &c.

THE experiments were made with the model of a waggon, whoſe weight, with the wheels, and a load (placed in the centre of the waggon), was eighty-two ounces. The wheels, in all the experiments, being to the uſual wheels on a ſcale of two inches to a foot. The height of the horſe's ſhoulder being on the ſame ſcale, four feet two inches the medium height—the draught from the fore-axle—the obſtacle half an inch high—and the angle of draught ten degrees above the horizon.

In this ſyſtem of experiments, the changes were rung among wheels of every common dimenſion; and it is rather ſurpriſing to find ſo little ſuperiority or inferiority in all the variety of combinations of heights in fore and hind wheels. Fore-wheels, however, of four feet eight inches, and hind-wheels of five feet ſix inches, ſeem to have what little advantage there is.

In putting theſe ideas into actual practice, it may be objected, that many inconveniences would ariſe to the coachmaker in altering the routine of his buſineſs, and putting his hands out of the train in which they had been uſed to work: if this were a general caſe, a bar muſt be put in the way of all improvement. But here no great departure is required from the general practice. It is certainly as eaſy to fix the ſplinter-bar *under* the futchels, as *upon* them. And I ſee no great outrage that would be done to appearance and faſhion, if the buttons on which the traces are looped were *under* the ſplinter-bar, inſtead of being a-top. In theſe caſes the draught would have all its mechanical advantages, and the horſes would draw agreeably to their form and anatomy: the pole would have the ſame command of the carriage down-hill, and the ſame command in turning, as in the preſent method.

SECTION XI.

Experiments to eſtimate what the Draught of Carriages is on different Kinds of Roads, and on different Declivities.

BEFORE we enter upon this eſtimate, it will be neceſſary to ſtate a theorem reſpecting all declivities whatſoever. A hill being but a continued obſtacle, and its reſiſtance overcome by gradation inſtead of abruption, or all at once, that reſiſtance may be repreſented by a right-angled triangle, fig. 7, Plate XIII. *B.* whoſe baſe *a b* is the level of the horizon, the hypothenuſe *a c* the declivity: now the ſum of the draught required from *a* to *c*, would be equal to ſurmounting the obſtacle *b c* all at once; and hence we find that the reſiſtance which hills make to the draught, is as the length of the hill to its perpendicular height, agreeably to the doctrine of the wedge or inclined plane.

The hill *a b* riſes one foot in three; for *a b* is three times *b c*. Now, agreeably to the doctrine, That the difficulty of draught is as the length of the hill to its height, it follows, that the wheel *D E*, fig. 8, Plate XIII. would be put in motion on the inclined plane *a b* with one third of the power that would lift it, and its load, perpendicularly, up any part of the line *c b*. In this caſe, the mechanic truth is verified, That what we gain in power we loſe in time; or that we only ſubſtitute a quantity of motion in the place of a quantity of power; for if I can roll the wheel *D E* up the inclined plane with one third of the exertion that would be neceſſary to lift it the ſame height perpendicularly, I muſt move it three times as far. The ſame rule holds good conſidering the ſpokes of the wheel as the acting parts of levers. The angle *e* is equal to the angle *n*, agreeably to the known truths of geometry; and the centre of gravity of the wheel *s* will have its line of direction in *s o z*; for that is the direction in which it would fall. Now a line drawn perpendicularly from *s o* to *r*, will be the ſine of the arc *o r*, and be the reſiſting part of the lever to the ſpoke or radius *s r*; for where the wheel touches the inclined plane, that place may be conſidered as the fulcrum of the lever *s r o*. Here the ſame rule holds good as in the inclined plane; the acting part of the lever *s r* is three times the length of the reſiſting part *o r*, and ſerves further to confirm the doctrine, That the reſiſtance of hills is as their length to their perpendicular height.

SECTION XII.

Miſcellaneous Obſervations on the Excellences and Defects of Wheel Carriages in general.

DISHED wheels, when on ſtraight or horizontal axles, have many excellences: they make carriages to ſtand on a broader baſe, and are leſs liable to overturn; they give more room to the body of the carriage, than if the ſpokes were perpendicular; they ſtand againſt ſide-jolts like an arch, and when the carriage goes on the ſide of the road, inclining on one ſide more than the other: or when the centre of gravity of the load lies over on one ſide, diſhed wheels may be ſaid to exert a degree of ſtrength proportionate to the weight thrown upon them; for then the ſpokes on that ſide become perpendicular, and, of courſe, more capable of ſuſtaining the additional load: but when the carriage is on level ground, and the centre of gravity equally diſtant from the fore and hind axle, each wheel ſuſtains a fourth of the weight; and hence, though at that time the ſpokes ſtand inclined, they are very capable of ſuſtaining the weight. But if the ſpokes were perpendicular to the nave, they would be better ſtill; only the ſpokes that ſuſtain the fellies ſhould ſtand alternately on each ſide the perpendicular, as fig. 9, Plate XIII. Such a wheel is an arch both ways; and as wheels that are diſhed are as liable to lateral obſtructions on their weak as on their ſtrong ſides, therefore a wheel armed on both ſides, as the fig. 9, is certainly ſtronger, has leſs wood, and is lighter in proportion to its ſtrength. The mail-coaches have, in part, adopted this idea; and in country roads it is certainly very uſeful; but in London, where coaches crowd like the people, the naves would be perpetually claſhing.

The bent fellies (when wood is not hurt by heating) are an improvement; they are ſtronger, with leſs wood; lighter, and, of courſe, eaſier of draught.

As to friction-rollers, poliſhed and turned boxes and axles, they are all expenſive nonſenſe. Friction-rollers ſoon wear into ſections, and then they are worſe than the clumſieſt box. And though artiſts would perſuade us that boxes may be made ſo cloſe and tight, that the axles ſhould fill them with ſuch nicety, that no ſand, or even water, can get in, experience ſhews it impoſſible. They will pleaſe for a ſhort time; but they will ſoon become like any common axle: theſe, and leathern boxes, are pleaſant, becauſe they leſſen the uſual noiſe of a carriage; but they are only temporary. The axles ſhould be poliſhed, and fit the boxes pretty cloſe; but not ſo cloſe that the attraction of coheſion ſhould impede their motion: indeed, the friction of axles, in carriages, is, in general, ſo trifling, that any perſon converſant with mechanics ſtands amazed that ſo much attention has been paid to it. If an iron axle be made to fit its boxes pretty accurately, and, by the ordinary methods, ſand and impurities be prevented from getting into them, and kept well lubricated by greaſe, there needs little more attention to the axles of wheels.

It has been ſuppoſed that carriages hung very high, were drawn eaſier than thoſe that hang low. If ever this idea had any influence in an informed mind, it muſt have been from the greater radius of a circle, in which an high carriage acts than a low one. See fig. 11, Plate XIII.

If the centre of gravity of the carriage was naturally at *a*, as it ran along the plain *B*, if it met with the obſtacle *d*, it would be lifted almoſt perpendicularly to *b*; but if the centre of gravity was as high as *c*, it would not be lifted, but thrown back, as it were, to *d*. The check given to the horſes, when an high-placed carriage is thrown back, is rather worſe than if the centre of gravity was lower: and it is obſervable that nothing checks the noble ardour of a horſe ſo much as ſudden jerks in his draught. The variety of over-turns, and the numberleſs necks and limbs that have been broken by means of placing the centre of gravity of the load ſo high above its baſe, have at laſt convinced the public, in general, of the inutility of the faſhion; and, accordingly, the bodies of carriages are placed now much lower than they were ſome years ago. And if they were lower ſtill, and the axles made longer, they would be ſtill leſs liable to be overturned; the carriages might be more roomy; and by having more ſpace to lay ſide-wiſe, would remove the jolts cauſed by the collar-braces in the preſent faſhion. It may be ſaid, in favour of high-placed carriages, that they keep the riders out of the duſt, and give them a proſpect of the country. For thoſe who ride out only for pleaſure, or an airing, I grant theſe are conſiderations; but it is not for them I write; I wiſh to be inſtrumental in eaſing the weary traveller, and the more weary horſes that draw him.

Short carriages, alſo, ſtill are conſidered as of eaſy draught: fore and hind wheels were lately brought ſo cloſe, that there was ſcarcely room to get into the carriage. This is alſo in the liſt of errors. For if the weight be the ſame, the frictions and reſiſtances will be the ſame, whether the carriage be ten yards or five in length. It is true, a few inches taken from a perch may make it a few pounds lighter, and alſo a few pounds ſtronger ; but this is not the motive, it is to make it *follow better*, according to the language of the ſtable.

Carriages leaning forward have alſo been thought to aſſiſt the horſes. This poſition is painful to the riders, and gives no eaſe to the horſes.

Sharp made the maximum of a carriage-wheel two feet diameter; Moor, eight: perhaps they were both wrong. The ſmall wheels muſt require an intolerable draught in ſoft or ſandy roads : and the large wheels would tire the horſes up-hill, and break their backs down-hill; for, if they are very high, they muſt be proportionally ſtrong and heavy, ſo that though their ſpokes may be conſidered as the acting part of levers, their weight overcomes all their mechanical advantage.—Mankind, by degrees, come to what is right; five and half or ſix feet is certainly the maximum of a wheel, and our cart and waggon wheels have long reſted at that ſize. A wheel ſix feet high muſt be nearly double the weight of one three feet ſix inches high, to be equally ſtrong :—hence a query ariſes, where the maximum meets of ſtrength and power, and of power and ſtrength? For if the wheel *s*, fig. 8, Plate XIII. and the weight upon it, be of the ſame weight as another wheel, *D*, and the weight upon it; and that equal in weight to the wheel *E*, and the weight upon it; now though *D* is double the diameter of *s*, and *E* three times its diameter, they will on the ſame declivity be drawn up ſingly with the ſame weight: allowing a ſmall matter for friction, which is greater in a ſmall than in a large wheel. But when the boxes of wheels are well made, and well greaſed, the friction is not above one pound for every cwt. of the carriage and load, and therefore a trifling object in any ſized wheel. But though the wheel *s* and its load weighed one ton; and the wheel *E* (three times the diameter of *s*) and its load weighed one ton, and could be dragged up the inclined plane *a b* with the ſame weight; yet the quantity of timber required in the tall wheel, to make it equally ſtrong with the ſmall wheel, would make its weight a greater diſadvantage than any advantage derived from its height; for the low wheels of 8 cwt. would ſuſtain and carry a load of 12 cwt. with nearly the ſame ſafety, or danger of breaking down, as the wheel *E* (three times its diameter) of 12 cwt. would ſuſtain and carry away a load of 8 cwt.

A faſhion has lately ſtarted up, where ſtage carriages run on eight wheels. We do not find that millepedes run ſo faſt as two and four legged animals, nor do I think this eight-legged machine has any advantage over thoſe of four. The friction is unneceſſarily increaſed, both of the firſt and ſecond kind. For a low wheel that turns twice round, while a larger one turns but once, muſt have double the *rubbing friction*; and if it be but half as high as another, it will have double the *friction by contact* on ſandy, ſoft, or ſtony roads. Theſe impediments, multiplied by 8, become formidable. This is another added to the many oppreſſions under which horſes labour. The roomineſs of the carriage admits a number of paſſengers, in proportion to the number of horſes that draw them: and it makes no jolt at a hollow place in the road; becauſe, when the firſt wheel goes over it, it does not deſcend into it, but goes ſtraight over without touching; when the ſecond wheel comes to the hollow, the carriage is ſupported by the 1ſt, 3d, and 4th wheels, ſo the ſecond paſſes over without touching; and thus of the reſt: by this means the carriage keeps more on a level, and freer from jolts than any other carriage. This ſort of carriage has begun already to be placed on four large wheels, for in its original conſtruction it might, from its novelty, be the whim of a few months, but on that conſtruction it cannot laſt long.

Single-horſe carriages are as little free from mechanical errors as thoſe of an higher claſs.—The ſprings and other accoutrements ſeem more calculated to enhance the price of the vehicle, than to make it laſt, or be eaſy to either the horſe or riders. It would be vain to go into a detail of all the faſhionable vagaries which have diſtinguiſhed this machine, growing as it has from a noddy to the preſent curricle. As the riders in this like to get up in the world as well as their neighbours, a ſtage, as it were, muſt be erected on ſhafts or on the axle, to ſet the body as high above the axle as poſſible; by which the riders ceaſe to jump up and down as formerly, the trotting of the horſe giving them a motion backwards and forwards horizontally, ſo uneaſy, that many wonder why their backs ſhould ache ſo ſeverely in riding a few miles in this carriage; if they will conſider the human back bone as a ſeries of hinges, playing with this abſurd and unneceſſary motion, the wonder will ceaſe.

Some again believe if this kind of carriage leans forward, it will puſh on the wheels. To ſuch as reaſon thus unmechanically, it is in vain to offer reaſon.

SECTION XIII.

IT may be expected, after the various faults I have taken the liberty to find with the preſent mechaniſm of wheel carriages, I ſhould offer ſome medicines for their defects and diſeaſes. I muſt here, however, do juſtice to the workmanſhip and decorations of our wheel carriages; being confeſſedly, in theſe reſpects, ſuperior to all nations. For carriages of ſtate, our country is applied to from every civiliſed nation on earth. The diſpoſition of our ſprings, both ſerpentine and ſpiral, for ſhow and elegance; our carving, gilding, and varniſhing; in ſhort, in every thing where the eye is to be captivated, and where ſhow and ſtate are the objects, we are unrivalled: but, unfortunately, theſe things ſeem to have abſorbed or ſwallowed up every thing elſe belonging to a carriage. We ſeem to have loſt ſight of its original deſign; or, rather, the eye is perverted from the main object, and the lace and ruffles become the only parts to which we attend. In what I am going to ſay, however, reſpecting what I apprehend to be an improvement in coaches, I muſt beg leave to be underſtood that ornament and decoration are out of the queſtion. 'Tis the eaſe of the riders and horſes I aim at; the ſtrength and lightneſs of the carriage; its cheapneſs and durability.

In the firſt place, I explode the perch; I pronounce this heavy and unwieldy piece of timber an uſeleſs load to the horſes. Why ſhould not the bottom of the body anſwer all its purpoſes?—and the fore-ſprings the purpoſes of a crane-neck?

Suppoſe the bottom part of the body, i. e. the timbers and ſpring of it, formed ſomething in the manner of fig. 1, Plate XIV.: *a a* fore-ſprings united by the bar *b*, to which the fore-axle is attached by the bolt *c*; *d d* leathern ſtays, to prevent ſide-jolts from affecting the body of the carriage.

There are ſtays for the fore part, but faſtened under the ſeat of the coachman, ſo as not to be expreſſed in the above drawing.

The ſhape of the bottom, and ſprings of the coach, may be underſtood from fig. 2, Plate XIV.

It may be aſked, what advantages theſe carriages have over thoſe of the preſent faſhion?

In the firſt place, I eſtimate they may be built, with every uſual convenience and decoration, for two thirds the price of coaches of the ſame ſtyle.

2d. They will be conſiderably eaſier of draught.

3d. They will be eaſier to the riders.

4th. They will be leſs liable to overturn.

5th. They will laſt longer than coaches made in the uſual way, becauſe the whole is ſupported upon ſprings; whereas the carriage-part of all coaches, at preſent, not being eaſed by the ſprings, ſtrike, in a manner, ſo dead and unyielding againſt obſtacles, that the carriage is knocked in pieces long before the body of the carriage, becauſe the body is ſuſtained by ſprings.

6th. It will be as eaſy to the coachman as to the inſide paſſengers; which will alſo give much facility to the fore-wheels in ſurmounting obſtacles. Whereas, in the preſent mode, an heavy coachman and a loaden boot are perched over a ſmall fore-wheel, and that preſſed down to the ground by the futchels acting upon it as a lever (as before deſcribed). I heſitate not to pronounce that fore-wheels ſo loaden would require double the draught that theſe would, *with the ſame weight.*

7th. Theſe carriages will turn in leſs compaſs, than carriages with perches.

8th. I eſtimate their weight at two thirds of thoſe of the preſent faſhion. Of courſe their *vis inertiæ*, ſo diminiſhed, muſt be friendly both to their draught and duration.

9th. A ſmall window on each ſide of the coachman, will give the riders an opportunity of looking out forwards; and a lantern hung in the front of the coachman's footſtool, will enlighten that part of the road where the horſes are to tread. Whereas three lamps hung in the preſent way are of little ſervice to either the coachman or his cattle.

10. The pole is a moſt unnatural mode of turning the carriage, and of retarding its motion down-hill: a pair of ſhafts for each of the two hindmoſt horſes, attached to the ſplinter-bar by hinges as in a common chaiſe, would anſwer every purpoſe; they would

turn the carriage in leſs compaſs than by the pole: both horſes could act together in retarding the carriage down-hill; for by leathern ſtays from one ſhaft to the other behind each horſe, all the purpoſes of breachings would be anſwered better, and with a tenth of their expence. The end of the pole bobbing and jumping againſt the heads and noſes of the poor horſes, teazes and peplexes them exceedingly, and their draught is increaſed by ſuch a heavy lever projecting ſo far from the fore-wheels. Whereas a pair of light ſhafts would neither teaze the horſes, nor hurt them by their weight.

END OF THE THIRD LECTURE.

LECTURE IV.

ON CHEMISTRY.

I FEEL a diffidence in the following explanations, conſcious how much I am obliged to deviate from the received, or rather the new, documents of chemiſtry. For being able to find little difference between the phlogiſton of the old chemiſts, and the caloric of the new, I have made the word *fire* to anſwer both.

Phlogiſton was conſidered as fire united to ſome *unknown* ſubſtance. *Lavoiſiere* ſays, *caloric* is that exquiſitely elaſtic fluid which produces *heat*. Am I excuſed in calling theſe plain *fire?* Fire, as it is generally produced on the earth, is known to be impure, and united with much terreſtrial matter; and, therefore, may have given riſe to the idea of an *unknown ſubſtance* being united to the ſimple element. This element of fire having its chemical affinities in common with groſſer bodies, enters more abundantly into ſome than into others; hence ſome bodies are more combuſtible than others, from containing more quieſcent or latent fire; and therefore when that fire is extricated from ſuch bodies, it brings much of their groſs matter along with it. But when fire is united with the volatile and finer parts of terreſtrial matter, it transforms it into that thin fluid we call our atmoſphere. Fire therefore aſſumes various appearances, and produces various effects; but ſtill I conceive the element to be identical, ſimple, unchangeable, deriving its various character from the ſubſtances with which it is combined. In ſhort, in its elementary ſtate I conceive it to be electricity, and I hope to prove that electricity is derived from the ſun.

To aſſiſt thoſe who would make a more complete ſcrutiny into this moſt uſeful branch of natural philoſophy, than can be in an elementary treatiſe, I ſhall firſt endeavour, by obſervations and experiments, to explain ſome of the general terms of chemiſtry.

SECTION I.

ACIDS are both in a liquid and concrete form, have a ſour taſte, and effervеſce with alkalis. Perhaps the acid principle, oxygen, is identical, and only differs by being combined with different ſubſtances: when procured from ſulphur, it is called ſulphuric acid; when diſtilled from nitre, the product is nitrous, or (when very ſtrong) nitric acid; when from ſea ſalt, it is marine acid; when from galls, the gallic acid; from ſorrel, the oxalic acid, &c.

Vitriolic or *ſulphuric acid* is fluid, tranſparent, colourleſs, greaſy to the touch, and without ſmell, like water, but twice as heavy. It is generally obtained from ſulphur by diſtillation or burning: for the laſt, vital air muſt be preſent to maintain the combuſtion; the veſſel muſt be cloſe; and water muſt be preſent to imbibe the acid. There muſt be one part of nitre (to afford vital air) to eight parts of ſulphur, in a proper veſſel, encloſed within a chamber of conſiderable ſize, and lined, on all ſides, with ſheet-lead (becauſe vitriolic acid will not attack lead); there muſt alſo be a thin ſtratum of water covering the bottom of the chamber to attract the acid, as it riſes in fumes from the burning brimſtone. This combuſtion repeated, the water becomes oil of vitriol, as it is called, from pouring like oil, and feeling like ſoap between the fingers. This liquor diſtilled, concentrates the acid; and is the vitriolic acid of commerce.

Nitrous acid is detached from ſaltpetre by the vitriolic acid ſeizing the alkaline baſes of the nitre. The nitre is moiſtened with vitriolic acid in a glaſs retort, with a long neck, to which, if heat be applied, the acid will riſe in brown vapours, and condenſe into a brown liquor in a receiver. This is the ſmoking nitrous acid, which if weakened by a little water, becomes aqua fortis.

Marine acid is detached from table ſalt by one third its weight of vitriolic acid, as in the proceſs for making nitrous acid (or by Woulfe's apparatus). The gas comes over without heat, and ſhould be received in water, which will greedily abſorb the gas, and become marine acid, of a lemon colour, and of a ſmell like ſaffron. This ſalt (like nitre) contains both an acid and an alkali; but its alkali has a greater affinity to the vitriolic acid than its own; the marine acid is, therefore, diſlodged from its native alkali, and unites with the water. The marine or muriatic acid forms with ſoda the common table ſalt, of a cubical form, and is three ways procured, viz. it is dug out of or drained from mines, and is called *rock ſalt*; it is procured from ſea water evaporated by the ſun, and called *bay ſalt*; and laſtly, from ſea water by boiling, and called *white ſalt*. This acid will combine with the volatile alkali or ammoniac, and then has the property of making tin very readily unite with iron and copper, under the name of *tinning* utenſils of thoſe metals. This acid combined with the nitric acid forms an acid different from both, called aqua regia, that will diſſolve gold, platina, &c.

Oxalic acid, or acid of ſugar, is procured by the action of nitrous acid on ſugar; it ſeizes the alkaleſcent particles of calcareous earths, and is the beſt teſt for diſcovering lime, chalk, marble, &c. in water.

Gallic acid is in the gall nut; an aſtringent principle, that has a ſtrong attraction to metallic oxyds, and precipitates iron from its ſolution, of a fine dark blue or black powder, which ſuſpended in water by means of gum, makes the common writing ink.—Decoction of galls, or oak bark, contains the matter called tanning, or the tanning principle.

ALKALIS are ſaline ſubſtances, that combine readily with acids: in a concrete form they attract moiſture from the atmoſphere, and become fluid: they have an acrid burning taſte; fuſe with a moderate heat; diſſolve earths with a ſtrong heat; become glaſs, when mixed with flinty ſubſtances, and expoſed to a conſiderable heat. They change vegetable infuſions to green; and they render oils miſcible with water.

Fixt mineral alkali forms one-half of ſea or table ſalt. It is detached from the ſalt by double its weight of litharge (or calcined lead), which, after they are triturated with water, and have ſtood for ſome hours, a decompoſition will enſue; the acid will attach itſelf to the metallic calx, and the alkali remain in the water; which, on evaporation, will leave a greeniſh-yellow pigment.

Vegetable fixt alkali are ſalts found in the aſhes of all vegetables, and much the ſame as mineral alkali. Pot-aſh is from the aſhes of wool; kelp, from fern aſhes; and ſoda, from kali, a marine plant.

Theſe aſhes, mixt with pure water, have their ſalts diſſolved by it, which, after filtering and evaporation, leaves the ſalts behind. This alkali boiled with quicklime, loſes its fixt air (and the lime acquires it); it is then ſaid to be cauſtic, becauſe in ſtriving to acquire fixt air, it corrodes and tears all animal ſubſtances with which it comes in contact. This alkali forms ſoap with oil, or oily matters; and with ſilicious earth, flint-glaſs. Is particularly uſeful in waſhing, bleaching, and medicine.

Tartar is the eſſential ſalt of wine, which, when burnt, is alſo an alkaline ſalt, that has ſo ſtrong an affinity to water, that it will attract it from the air, and become a complete ſolution: it has then been called oil of tartar by deliquium. If tarter be boiled to ſolution in water, and ſuffered to cool gradually, it will cryſtallize beautifully, and is called the cream or cryſtals of tartar.

Volatile alkali. This alkaline ſalt is procured by decompoſition from all animal, and ſome vegetable ſubſtances; and by putrefaction. (See Affinity.)

SOLUTION is a property of *fluids*, whereby they imbibe, or incorporate, themſelves with *ſolids*; ſeparating their parts, and becoming homogeneous, or as if the particles of the ſolid were the ſame as the particles of the fluid. The ſea is a ſolution of ſalt in freſh water. Ink is a ſolution of vitriol and galls in water. Diluted nitrous acid diſſolves copper, making a ſolution of copper. Quickſilver diſſolves lead. Gold diſſolved in aqua regia is a ſolution of gold; and ſpirit of wine incorporates with camphor. When there is a greater attraction between the fluid and ſolid, than between the particles of the ſolid itſelf, the particles of the ſolid are ſeparated, and detached through the fluid, and both become fluid.

The particles of water are conceived to be round, from the fluid imbibing a quantity of foreign matter without its bulk being increaſed; for if ſalt, and then ſugar, be ſcattered ſlowly into water, ſo as to have time to diſſolve, the water will almoſt imbibe its own bulk of the ſalts before it will appear to ſwell. The manner of this incorporation may be explained by making the particles of water to be repreſented by a glaſs full of marbles, and pouring in ſmall ſhot amongſt them to perſonate the ſalt, or any thing elſe incorporated with water. This may give alſo an idea of all mineral or other waters which derive their character from imbibing, mechanically, or chemically, the fine particles of the different ſtrata over or through which they paſs in the bowels of the earth: for the ſimple element is the ſame in all places, and only has a character from attracting and incorporating itſelf with the fine particles of the ſubſtances with which it has affinity, or with which it comes in contact and mixes mechanically. Hence chalybeate ſprings are of water that has run over iron, or iron-ſtone; and though it may be quite tranſparent, it will turn blackiſh with a few drops of an infuſion of galls in ſpirits of wine. The acid of this aſtringent vegetable unites with iron, its ore, its calx, or ſalt; and the ſolution abſorbing the light that falls on it, produces blackneſs, being the ſame as ink.

Thames water inſinuates itſelf through its gravelly banks a conſiderable diſtance from its bed; ſo pumps, at ſome miles diſtance, draw up Thames water. In many parts of its progreſs it runs over chalk and ſelenitic beds (gypſum), which give it both an acid and alkaline quality in a ſmall degree. The acid is diſcoverable by a few drops of a ſolution of tartar (oil of tartar): this alkali ſeizes the acid, and deſcends with it in a cloud to the bottom of the glaſs, where ſtanding ſome time, it concretes into a neutral ſalt. The alkaline part is diſcoverable, in a long glaſs, by a few drops of a ſolution of the acid of ſugar, when the precipitation is exhibited in long, wavy, and ſtriated ſtrings of ſingular beauty. This acid has ſo ſtrong an affinity to calcareous earths, that the ſmalleſt poſſible quantity of it in water is detected by it. This acid alſo attacks the teeth (as calcareous matter), and hence their blackneſs in thoſe who indulge with ſugar.

Many other teſts diſcover acid and alkali in water, as ſyrup of violets, tincture of turnſole, &c. With the firſt water a polarity is formed, that qualifies the mixture to tranſmit red light; with the latter, green light.

Bath water is warm, and chalybeate: theſe properties are derived from the beds of pyrites (or fire ſtones) through which rain water paſſes in the bowels of the ſurrounding hills. This ſtone contains iron and ſulphur: from the iron it derives its chalybeate quality; from both its heat. If a heap of theſe ſtones have water thrown on them, they will ſet fire to any combuſtible body in contact with them; for ſulphur containing much fire, and vitriolic acid in combination with it, theſe qualities lie dormant till ſome medium forms a chemical union between them and the iron; this is water, which gives the iron a vehicle through which to draw the latent acid from the ſulphur, between which there is a ſtrong affinity. The ſtone, by this means, becomes ſlowly decompoſed, the fire of the ſulphur is evolved, gives out ſenſible heat, and the water carries that heat to the ſurface. A continual flame is produced by pyrites in a place near the road between Florence and Bologna; and from the ſteamy appearance of the ſmoke of Veſuvius, in the time of an eruption, it is more than probable that pyrites and water are the principal ingredients in that wonderful and alarming phenomenon!

Spa, Pyrmont, and Seltzer water, owe their medicinal, acidulous, and ſparkling qualities, to fixt air. They alſo contain a little iron, magneſia, and common ſalt: theſe are detected by gentle evaporation. Theſe waters can all be imitated by art; for chalk, marble, and all calcareous earths, hold fixt air in combination, and which can be forced out of them by ſtronger acids. If a little bruiſed chalk, in a bottle with a crane neck, have vitriolic acid diluted with water put to it, the air will be extricated, and may be let into the inverted jar of water, fig. 1, Plate XV. This jar being ſhook while it receives the gas, the water in it will imbibe the air, and become acidulated like that of Pyrmont. This gas is alſo *forced* into common water, ſo as to become much ſtronger than the natural Spa waters. See fig. 3, Plate XV.

Aix-la-Chapelle, or Harrowgate water. Sulphur, or rather hepar ſulphuris, is the major ingredient in theſe waters; but as water will not diſſolve ſulphur, how come we by its ſolution? Hepar ſulphuris, or liver of ſulphur, is compoſed of equal weights of ſulphur and pot-aſh fuſed together in a crucible. The alkali looſens the latent fire of the ſulphur, by its ſtrong affinity to its latent acid; and hence when the hepar is expoſed in air, or water, a portion of that fire is carried off, and the ſulphur precipitates, as ſeen in the encruſtations on the waters of Aix. Three parts of iron filings, and two of ſulphur, melted in the ſame way, anſwer equally well: the maſs being bruiſed and diſtilled as in fig. 1, Plate XV. will yield a gas which the water will imbibe, and become hepatic water, ſmelling like rotten eggs, and curing ſcorbutic diſorders. A few drops of nitrous acid decompoſes this water, it ſeizes the alkali, and the ſulphur falls to the bottom. It is hard to ſay how ſuch a proceſs as this is carried on in the bowels of the earth. Beds of pyrites are decompoſed by water with heat:—Would not this heat and ſulphur, in a bed of peatmoſs (vegetable matter), produce a hepar capable of uniting with water? Water alſo diſſolves air; but the union ſeems not chemical; for take off the preſſure of the atmoſphere from the ſurface of water, and the air inſtantly ſprings up from the water; ſo it appears as if it had only been forced mechanically into the water by the weight of the atmoſphere.

DISTILLATION is the application of heat to ſeparate fluid and volatile parts from bodies; and to condenſe and collect them in other veſſels by means of cold. Heat expanding all bodies, and putting their particles into a repulſive ſtate, when this application becomes more powerful than the coheſion of the body, a ſeparation takes place; the lighter parts riſe in ſteam or gas, and the heavier remain. Liquors that have gone through a ſtate of vinous fermentation, as wine, beer, &c. are diſpoſed to part with ſpirit by a gentle heat, and are put in the Still, *a*, fig. 2, Plate XV. The fire *b*, rarefies the wine into ſteam, which may be repreſented by the little ſtars and circles within the Still *a*; the ſtars as particles of repulſive fire, and the circles as the particles of the wine. Theſe are puſhed into the ſtill-head *d*, and thence into the pipe *g*, and along the ſpiral pipe within *c*, till they make their exit at *z*. Hence the worm-tub, *c*, being kept always full of cold water, this condenſes the ſteam within the worm, ſo that it comes out a regular fluid at *z*. Diſtillation may, therefore, be called a warfare between the repulſive power of heat, and the condenſing power of cold; for the liquor riſes in a very attenuated ſtate in *a*; becomes more and more compact in the worm, till it ceaſes to be ſteam at *z*. Spirit riſing with leſs heat than water, comes over firſt, as may be ſeen by holding paper dipt in it to a candle; but when the watry part of wine comes over, a paper ſo dipt will extinguiſh the candle: the tartar remains at the bottom of the ſtill: ſo we find red-port conſiſts of ſpirit, water, and a ſalt.

Sea water expoſed in a retort, on a fire, comes over freſh, and the ſalt remains in the retort, and would melt before it would riſe. This is, in miniature, the mode of manufacturing table ſalt. Hence grapes, after fermentation, produce brandy, and ſpirit of wine; ſugar-canes, rum; and barley, gin.

SUBLIMATION is but a diſtillation of dry ſubſtances. *Sulphur* in a cloſe veſſel, with a long chimney, melts with a gentle heat, and riſing, adheres to the chimney, forming flowers of ſulphur. *Phoſphorus* juſt covered with water in a Florence flaſk, and expoſed over a lamp, ſublimes into the appearance of ſtars, and the aurora borealis. It riſes with the ſteam of the water, and ſtruggling to quit the water, and obtain the air, burſts into beautiful corruſcations in the flaſk, particularly when ſeparated from the lamp, and expoſed in the dark.

Gum benzoin, melted in the pot *a*, fig. 3, Plate XV. on the hot iron *e*, will ſublime on the ſprig of roſemary in cryſtals like needles, ſurrounding every branch like a beautiful hoar-froſt.

Zinc, when melted in a crucible, by a hot fire, ſublimes in flocculæ, like pieces of cotton wool.

Saturation ſignifies the point at which the attractive and diſſolving power of any menſtruum ſtops, when filled with the matter it is to diſſolve. Solutions of ſalt or ſugar in water, of ſulphur in oil of turpentine, camphor in ſpirits of wine, ſilver in aqua fortis, water in air, &c. are tranſparent till fully ſaturated; if more be added, they ſink in their natural form to the bottom undiſſolved, and the menſtruum is ſaid to be fully ſaturated. If water, ſpirits, oil, &c. be evaporated from the matters with which they are ſaturated, theſe matters aſſume their natural form: common ſalt, a cubical form; nitre, the form of a priſm, &c. &c. adhering to the bottoms and ſides of the containing veſſels.

Cryſtallization ſignifies the various angular forms into which ſalts, fluors, metals, &c. go, when they depart from a diſſolved or fluid ſtate, into that of a concrete or ſolid form: in which ſtate, a part of the water in which they were diſſolved is neceſſary to their cryſtallization. This is called the *water of cryſtallization*, which being expelled by heat, or expoſure to the air, the ſalts loſe their cryſtalline form, and effloreſce into a mere powder.

Precipitation is performed in fluid matters only; it is a diſuniting of two or more ingredients by the addition of another, which, by its greater affinity, unites with one of the ingredients, and ſeparates the other from it, by which they generally fall to the bottom of the liquor, and are ſaid to be precipitated. Common ſalt thrown into water diſſolves and becomes incorporated through the whole maſs of water, as may be taſted. The ſalt cannot then be ſeparated from the water by filtration, or any other method merely mechanical: but it may be ſeparated by a very ſimple proceſs; pour into the ſolution ſpirit of wine, and the ſalt inſtantly falls to the bottom, and is ſaid to be precipitated. Water iſſuing from copper-mines, is generally much impregnated with the calx, or ore, of copper, which wants nothing but phlogiſton (or the inflammable principle), to become real copper. Ponds of ſuch water have bars of iron placed in them, which contain much inflammable matter, and which the calx of copper will ſteal by means of a ſtronger affinity. Hence the bars become covered with copper, and much is precipitated; while the iron becomes a calx, by having loſt its fire. Knives, or any poliſhed irons, dipt in ſuch water, appear to be converted into copper.

Calcination means the expoſing a body, in an open veſſel, to a ſtrong heat, till no further alteration or change can be produced in it. What remains and withſtands the fire is a calx. Bodies in which fire makes no change are called refractory.

Digeſtion is keeping bodies over a weak fire, that combinations may be effected by time rather than heat.

Cementation. If one or more ſolid bodies be pulverized, and expoſed to a ſlow heat in proper veſſels, the more volatile parts may be made to cement, as it were, or incorporate with the other parts.

Concentration conſiſts in increaſing the proportion of ſaline or other matters, by driving off the water in which they are diſſolved by heat, or cauſing it to freeze, and then removing the ice. For alcohol may be got from common rum or brandy, by freezing the water with which theſe ſpirits are united, and the alchol will be found in the middle of the ice.

AFFINITIVE ATTRACTION. Purpoſing to carry forward the mechanical and chemical philoſophy hand in hand, this lecture is devoted to the firſt principles of the moſt extenſive and uſeful branch of natural philoſophy: for all arts and manufactures are little more than the compoſition, or decompoſition, of the natural bodies of the earth. We are indebted for many of the important facts in chemical analyſis to a race of viſionaries, who, in the purſuit of the philoſopher's ſtone, and the elixir vitæ, happily ſtumbled upon a variety of diſcoveries, that have been of more importance to mankind, than the grand ſecrets they were in purſuit of would, had they been found out. Theſe facts, though now ſyſtemized into a tolerably regular and conſiſtent theory, ſimple in its principles, and, ſeemingly, accordant in its various ramifications; yet, I am ſorry to ſay, it does not *quite* agree with the experiments and obſervations that have fallen in my way to make. I think the grand baſis of chemiſtry is *attraction* and *repulſion.* By attraction, I mean not only that of coheſion and gravitation (formerly explained), but the affinities of matter; the elective attractions, or local affections of it, that is, the tendency which the conſtituent parts of bodies have to unite readily with ſome ſubſtances, in preference, as it were, to all other parts of matter. Water and ſpirits are ſaid to have an affinity, becauſe they unite with the utmoſt readineſs and affection. Water and oil have no affinity, becauſe they will not unite (except by the intervention of an alkali, by which they become ſoap) ; for if oil and water are ſhaken together, it will be found the parts of each attract thoſe of the ſame kind more ſtrongly than the other, and the two preſently ſeparate. Acids and alkalis have ſo ſtrong an affinity, that they ruſh into union with efferveſcence and ebullition ; ſo ſtrong, indeed, is the attachment between acids and alkalis, that one will detach the other from moſt compounds with which that other is united. The ſea is a compound of freſh water and ſalt ; yet ſo perfectly clear and homogeneous (as ſolutions generally are), that water and ſalt may be ſaid to have affinity. That this ſelection, this choice, as it were, is but a modification of the attraction of coheſion, I entertain no doubt ; for as various effects in chemical experiments prove the particles of matter to be of various ſhapes or forms, ſuch particles as by their figure can lie conveniently by the ſides of each other, or admit their centres coming nearer together, will adhere more ſtrongly than thoſe combinations where the corners and edges of particles do not fit, but incloſe great ſpaces or interſtices among them. This laſt may be called the attraction of coheſion ; the other the attraction of affinity ; but it is a diſtinction with little difference. See Plate V. in *Magnetiſm*, where the conforming ſides of differently ſhaped particles ſo adjuſt themſelves to one another as to become regular figures : ſomething like the irregular flat ſtones in the Flaminian pavement that make a regular highway.

1ſt. Spirit of wine diſſolves a large quantity of camphor without loſing its fluidity or tranſparency. The ſpirit is called the menſtruum, or ſolvent; but this menſtruum having a greater affinity to water than to camphor, upon the admiſſion of water to this ſolution the ſpirit forſakes the camphor, and uniting with the water, the camphor is ſaid to be precipitated, though it ſwims on the ſurface of the fluid. This effect is produced by ſimple affinity.

2d. Silver will diſſolve in diluted nitric acid (luna cornea), become homogeneous with it, or as clear as if it were one ſimple fluid: but nitrous acid has a greater affinity to copper than to ſilver; copper, therefore, put into this ſolution, precipitates the ſilver, which in precipitating ſhoots into thoſe beautiful ramifications called the Arbor Dianæ.

3d. Salt of tartar, mixt with ſalt of mercury (or ſublimate, as it is called), will form no union when dry; but mixt with water, a ſingular polarity takes place; they form an orange coagulum, unlike any of the ingredients: but the tartar is an alkali, and has a ſtronger affinity to an acid than to the ſublimate of mercury; hence a few drops of ſtrong nitric acid inſtantly diſſolves this union, the colour is diſcharged, and the whole becomes tranſparent.

4th. The ſalt of copper (blue vitriol) diſſolved in water, has no colour; but a few drops of the ſpirit of ſal-ammoniac gives it a polarity, that qualifies it to tranſmit blue light: this polarity is deranged by a few drops of the nitric acid; for by its ſeizing the alkali, the whole again becomes colourleſs. But to bring about its former polarity, and qualify it again to tranſmit blue light, if a ſtronger alkali (oil of tartar) be added, the colour will return.

5th. Salts inſtantly precipitate and cryſtallize when ſpirit of wine is added to their ſolution in water; for water has a greater affinity to ſpirit than to ſalt.

6th. Unions are often formed by two bodies, where their product is totally unlike either. Diluted vitriolic (ſulphuric) acid will attack iron, drive out its fire in the character of air, and, uniting with the iron, or rather its calx, form a ſalt unlike either the acid or the iron, called martial vitriol.

7th. Epſom ſalt (ſulphate of magneſia) conſiſts of magneſia united with the marine acid. When this ſalt is diſſolved in water, if ſalt of tartar (a ſtrong alkali) be added, it will ſeize the acid, and detaching it from the magneſia, the magneſia will be precipitated, or fall to the bottom of the ſolution, in the form of white powder. Or if an equal quantity of a ſtrong ſolution of Epſom ſalt be put to a ſtrong ſolution of tartar (oil of tartar), the union will form a ſolid, which is the magneſia of the ſhops.

8th. Nitre is decompoſed by the vitriolic acid (ſulphuric acid), for this acid will ſeize the alkaline baſes of the nitre, and form with it a vitriolated tartar. But the acid of the nitre, being thus forſaken, has its revenge; for if it be mixed with the vitriolated tartar, it drives out the vitrolic acid in its turn, and ſeizing its alkaline baſes, forms with it a true nitre, ſuch as exiſted before the operation. This is called reciprocal affinity.

9th. Common ſalt is a compound of marine acid and marine alkali; but this alkali (as above) having a greater affinity with the vitriolic acid, will, when it is poured in, forſake its own acid, and leave it, flying off in fumes. The new ſalt ſo formed is called Glauber's ſalt. Liver of ſulphur conſiſts of ſulphur and fixt alkali: water will not unite with ſulphur; but as fixt alkali has a great affinity with both ſulphur and water, it ſerves as an intermedium to unite theſe two ſubſtances together. Hence the ſulphuric waters of Aix-la-Chapelle, Harrowgate, &c. Theſe are common inſtances of this ſpecies of attraction. Three or four heterogeneous ingredients will, in many inſtances, attack one another, where affinity could only take place from the joint action of two againſt a third, or a fourth, ingredient; from which often reſults two decompoſitions, and two new combinations. This is called double affinity.

10th. To diſengage the volatile alkali from ſal-ammonic, if a mixture of two parts of chalk, and one of ſal-ammoniac in powder, be expoſed to a ſand heat, in a retort, adapted to a receiver, a change of principles will take place. The chalk conſiſts of lime and fixt air; the ammoniac of volatile alkali and marine acid. Both are decompoſed; the lime unites with the marine acid, and forms a fixt ſalt in the retort; and fixt air unites with the volatile alkali, and paſſes into the receiver, where it forms a white ſalt, of a pungent ſmell. This is the ſal volatile of the ſhops, and uſed for ſmelling-bottles.

Becauſe the laws of this, and the other ſpecies of coheſive attraction, do not ſeem to follow the laws of gravity (by diminiſhing as the ſquares of the diſtances increaſe), ſome imagine them of a diſtinct and different nature from the attraction that holds the earth and the planets together. But can ſuch ſmall maſſes as we can make our experiments upon, betray the ſame ſtrong phænomena as a world, a planet, or a ſun? Could we meaſure the ratio of the attraction, exhibited between two corks running to meet each other, when ſwimming on the ſurface of water, I entertain little doubt but it would be found to be in the ſame ratio as the laws of gravitation. Magnetic and electric attraction probably are the ſame alſo. Similar phænomena muſt ariſe from the ſame law, if we are not to multiply cauſes; which certainly is a moſt excellent rule in philoſophizing, or examining nature.

Objections are alſo made to fire and light being the ſame, becauſe heated iron exhibits no light till it becomes violently heated. Fire lying in a latent ſtate in metals, muſt be ſtrongly excited by external heat, before it will betray ſigns of activity, or ſenſible light; for metals have ſo ſtrong an affinity to fire, and retain it with ſo ſtrong an attraction, that they muſt be attacked with great violence by external fire, or force, before they will part with their own.

11th. If a piece of wood and a piece of iron be put in the ſame fire, the wood will let out its light, in a white flame, in a few ſeconds; but the iron, from its ſtrong affinity to light, lets it out by degrees; the violet (as weakeſt part) is ſeen on its ſurface firſt; the heat increaſed, the blue part of light appears on its ſurface (at this ſtage it is frequently taken from the fire, the colour congeals on its ſurface, and hence we have utenſils and toys of blue ſteel, &c.); the heat increaſing, the other colours, as green, yellow, red, will be expelled in priſmatic ſucceſſion: but when the heat becomes intenſe, the light is forced out altogether, and the iron becomes white; indicative of the mixture of the ſeven primitive colours contained in all light.

Affinities are not confined to the groſſer bodies of the chemiſts; they exiſt through all nature. Electricity, light, fire, air, water, &c. have all a tendency to unite with ſome bodies in preference to others. We ſee, then, that one ſubſtance will diſlodge another, where greater affinity takes place; and that we can make tables of the relationſhip which one kind of matter has to another, and thereby know the reſults of moſt kinds of mixtures beforehand. For if a fixt alkaline ſalt be united with vegetable acid, as vinegar, and formed into a neutral ſalt; on adding to this compound ſome marine acid, the acetous acid (vinegar) will be diſengaged, ſo as to fly off in a moderate heat, leaving the marine acid in poſſeſſion of the alkali: if then the nitrous acid be added, it will, in like manner, diſpoſſeſs the marine, which will riſe in white fumes; though, without ſuch an addition, it could not be detached from the alkali by any degree of heat: but on the addition of the vitriolic acid, the nitrous gives way in its turn, exhaling in red fumes, leaving the laſt acid in full poſſeſſion of the original alkali.

From numberleſs affinities like theſe, that have been diſcovered by the labours and experiments of the laboratory, have reſulted the uſeful tables of affinities by Geofroy, Bergman, Black, &c. A ſpecimen of which can only be given in this work. The ſubſtance to which other ſubſtances are related is generally placed in capitals at the top of the table; and the next ſubſtance under it, is that to which it has the greateſt affinity; the next under that a leſs, and ſo on; thus:

Vitriolic Acid.	Nitrous Acid.	Lime.	Fossil Alkali.
Terra ponderoſa	Vegetable alkali	Acid of ſugar	Vitriolic acid
Vegetable alkali	Foſſil alkali	Acid of ſorrel	Nitrous acid
Foſſil alkali	Terra ponderoſa	Vitriolic acid	Marine acid
Lime	Lime	Acid of tartar	Phoſphoric acid
Magneſia	Magneſia	Phoſphoric acid	Acid of ſugar
Volatile alkali	Volatile alkali	Nitrous acid	Acid of tartar
Clay	Clay	Marine acid	Acid of ſorrel
Zinc	Zinc	Acid of lemons	Acid of lemons
Iron	Iron	Acid of benzoin	Acid of benzoin
Lead	Lead	Acetous acid	Acetous acid
Tin	Tin	Acid of borax	Acid of borax
Copper	Copper	Aërial acid	Aërial acid
Antimony	Antimony	Water, &c.	Water
Arſenic	Arſenic		Unctuous oils, &c.
Mercury	Mercury		
Silver, Gold, &c.			

That is, ſuppoſe *A* the principal ſubſtance to which the other ſubſtances are related; and the other ſubſtances are *B*, *C*, *D*, &c. Now if *A* be applied to two or more of theſe ſubſtances, *B*, *C*, &c. at the ſame time, and in quantity ſufficient to unite with each of them ſingly, it will generally unite to only one of them, as *A* to *B*, and diſregard the reſt. Sometimes *A* will attack both *B* and *C*, and divide itſelf between them; and ſometimes the compound *A B* being preſented to *C*, *A* will forſake *B*, and form an union with *C*, &c.

SECTION II.

Of Combuſtion.

WHEN heat is applied to wood, the inflammable principle of the wood (i. e. the light it had derived from the ſun) has that dormant principle of expanſion put into action by the heat; and if vital air be about it, combuſtion and decompoſition will take place; the wood (like every thing elſe) turning black, before it parts with its light to the ſurrounding ſpace. A ſmoke is produced, which is a mixture of water, oil, volatile ſalts, air, &c. And when the heat is carried to a certain point, the wood takes fire, and the combuſtion proceeds till the inflammable principles are diſſipated. In this operation there is a diminution of the air about it; and light, and its concomitant heat, are extricated. For as no inflammation will take place without air, air muſt mix itſelf with the heated vapour, before it will ignite into real flame. As reſins are a product of the ſun, the more there are in any vegetable, the greater will be the light and heat in the combuſtion. The ſoot produced in this proceſs conſiſts of parts imperfectly burnt, that are decompoſed only in part, and have eſcaped the action of air, and which may, therefore, be burnt over again. For when the combuſtion is perfect or effectual, as in Argand's lamp, there is no perceptible ſmoke. The fixed matter after combuſtion is aſhes, containing ſalts, earth, and often iron and other metals. Is not this proceſs, firſt diſturbing and then igniting the fixt light of the combuſtible body, by the near approach and contact of another body, already in a ſtate of heat and combuſtion? Muſt not coals, candles, wood, &c. be heated before they will ignite, and by which the light of the body to be burnt had its dormant repulſion excited? The body ſwells, admits the neighbouring ignition, and has its latent light let looſe or expelled in the character of flame; and is not this the light it originally derived from the ſun? Air being kept in a ſtate of fluidity, by the latent fire or light united with it, is neceſſary to the ſupport of flame. How? It adds fire to fire. For the fire contained in the air around the ignited body joins the combuſtion, and is alſo diſperſed; the air firſt ſwells, by its inherent fire being excited by heat, and then becomes diminiſhed in its volume, by loſing a conſiderable portion of that fire, and of courſe of that repulſion, which ſet the particles of the ſurrounding air at a diſtance. Why then ſhould we believe, with modern chemiſts, that the pure part of the air is univerſally abſorbed by the body in combuſtion? We find no air in the ſnuff of a candle, nor in the aſhes of coals or wood.

This doctrine is not meant to invalidate the well-known facts, that metals, while calcining, require a current of air to paſs over them; that they imbibe a portion of the pure air in that paſſage, and diminiſh air confined with them in cloſe veſſels, when calcining by the uſe of burning glaſſes. Theſe, and many other circumſtances, prove that air is imbibed by metals when in a ſtate of fuſion; and that they would not calcine to a calx, or oxyd, without pure air; and that it is that air, going into a concrete ſtate in the calx, that makes the oxyd of a metal, ſo calcined, heavier than the metal from whence it was made: for a pig of lead, 100 lb. weight, will produce 110 lb. of minium.

Though it is an article in our chemical faith, that nothing is deſtroyed; that the original particles of matter are the ſame as they came out of the hands of their great Maker; and that it is their various combinations that cauſe that variety we ſee in bodies;—I fear this is not ſtrictly true. Air certainly is diminiſhed, or loſt, or annihilated, where combuſtion is going on; and it is not to be found in the aſhes or cinders of burnt bodies. Yet theſe aſhes and cinders become again combuſtible by expoſure to light; for, ſo expoſed, they riſe again in vegetables, and all vegetables are combuſtible: thus may be verified the aſſertion, that "light unburns burnt "bodies."

Marble, chalk, ſhells, and all calcareous earths, may be ſuppoſed to have no affinity to fire or light; for they let out none in their decompoſition. When burnt in the fire, they may be made red hot, but they produce no flame: the fixt air, one of their conſtituent parts, extinguiſhes flame, and reſiſts the entrance of electricity. For fire propagates itſelf with moſt difficulty through ſuch bodies as refuſe to conduct electricity; and *vice verſa*. When calcareous earths are calcined, or burnt into lime, their fixt air and water are expelled, and fire is forced into their place. Hence a quantity of fixt fire becomes a quality of the quick lime, which ſleeps latent and inſenſible, till called into action by its ſtronger affinity to water: this applied, the calcareous baſis ſeizes its old friend, and expels the new, which flies off in ſenſible heat. Fixt air being alſo applied and imbibed, the maſs will become marble, chalk, ſhells, &c. again.

Thus we ſee that nature has two ways of cooling bodies, the one by diſſipating fire, the other by fixing it. For different bodies at the ſame temperature really poſſeſs very different quantities of fire, though they riſe the thermometer to the ſame degree; for ſome bodies have a ſtronger affinity to fire, and abſorb it in greater abundance, than others.

When we burn a combuſtible body to obtain heat, that heat is from the ignited body repulſed radiantly through the ſurrounding air, which air is preſſing towards the fire on all ſides, and ſupplying it with its vital part: hence a kind of contention takes place between the emanating particles of heat ruſhing from the fire, and the currents of air ruſhing towards it; for air of itſelf is a bad conductor of heat, and ſome conſider it a non-conductor of it. Fig. 3, Plate II. repreſents heat iſſuing from the fire by arrows pointing from the fire; while the motion of the air is repreſented by darts pointing towards the fire.

As fire propagates itſelf through metallic bodies more eaſily than ſuch as reſiſt electricity, we find that molten lead poured into a ſquare veſſel, three ſides of which are of wood, and the fourth of lead, the heat will penetrate the lead ſooneſt, and cool on that ſide ſooneſt.

That air is neceſſary to combuſtion, is exemplified in its mixture with the vapour riſing from a fire, or candle, and qualifying that vapour to become flame. For heat penetrating the wick of a candle, rarefies and ſends off a quantity of unconſumed oil in vapour. If a tube of paper, eight inches long, be held over the candle when blown out, and a lighted piece of paper be held over the upper end of the cylinder, the fire will follow the hot vapour down it, and light the candle.

The ſpecific fire contained in bodies being incapable of meaſurement by the thermometer, a means has been invented of aſcertaining it by the quantity of ice which bodies, at an equal temperature, will diſſolve in the ſame time. The difference of the quantity diſſolved is ſuppoſed to give the proportion of ſpecific fire contained in the ſeveral bodies. This inſtrument is called a calorimeter. Ice abſorbs all the heat communicated to it, without communicating any part of that heat to other bodies, until the whole is melted; ſo the ſpecific fire contained in bodies may be calculated by the quantity of ice which it will melt.

This inſtrument has its ice, and the bodies to be tried, ſurrounded by an incloſed cavity of air, to ſecure the materials from the action of the outward air, or heat or cold of contiguous bodies; for air and water may be almoſt ſaid to be non-conductors of heat. If the end of a red-hot iron be held perpendicularly, an inch diſtance, over a drop of water, on wood or metal, the water, wood, or metal, will receive no heat. Hence the lids of kitchen pans being made hollow (to contain more air), the heat cannot eſcape, and the contents within are heated, and kept ſo, with a ſmall fire.

Salts, perhaps, are the chief links uſed by nature for confining and fixing the ſubſtance of fire. What are pyrites in the mineral kingdom, but ſalts united with ſulphur, which being alſo united with a few metalic particles, confine a great quantity of fire? In the vegetable kingdom, does not common fire diſengage itſelf the more eaſily from wood, in proportion as that wood is deprived of its ſaline particles? The flame of wood, floated down rivers, burns clear, probably from the ſalts being diſſolved by the water: and rotten wood, decayed by lying in moiſture, emits light, by having loſt the tenacious links of ſalts, by which the fire was kept impriſoned. In conſequence of this diſſolution, fire is become enabled to diſengage itſelf by virtue of its expanſive force, though too weak to affect our ſenſes by heat. May not the loſs of ſaline particles, in fiſh going into a ſtate of putreſcence, develope their conſtitutional fire, and occaſion their luminous appearance? This light in wood, fiſh, or fleſh, becomes extinct when expoſed in vacuo, in extreme cold, and in ſpirits. Yet whenever a body reaches the proper temperature it becomes luminous, independent of any connection with air, for iron wire becomes red-hot immerſed in molten lead: but it will not burſt into flame without air. An earthen crooked tube immerſed in an iron veſſel filled with ſand, and made red-hot: if air be blown through the tube it will not be luminous to the eye; but when a gold wire is thruſt into the tube, the end of the tube will become luminous to the eye. Muſt not this be the inflammable matter of the gold, let looſe by the heated tube, and ignited in a degree by the hot air?

Sugar, and many other ſalts, have their fire expelled by rapid bruiſing: for fine ſugar chewed in the dark will make the mouth luminous.

Fire may be inſtantaneouſly detached from dry air, and made viſible, by tying a wet bladder over one end of an open cylinder of glaſs, drying the bladder, and putting an empty Florence flaſk under it, on the air-pump: when the air is nearly exhauſted in the dark, the bladder will burſt by the preſſure of the air upon it, and exhibit light on the flaſk, by the ſudden derangement of that air which ruſhes into the vacuum.

FIRE, like all other material ſubſtances, is ſubject to be attracted by other bodies; by this tie ſome of its properties are obſcured, and new ones produced. Like an acid, when ſaturated with an alkali, that cannot be diſtinguiſhed by its taſte, or any of its original properties; ſo fire loſes with its liberty (when abſorbed in other bodies) its chief property, the power of burning or producing ſenſible heat. This power, however, is only ſuppreſſed, not deſtroyed; for it will again aſſume its wonted vigour, when the bond of union is broken by combuſtion, ſtronger affinities, &c. Fire is capable of condenſation, as in gunpowder, pulvis fulminans, phoſphorus, &c. Nitre, charcoal, and ſulphur, are the ingredients of gunpowder. Nitre contains nearly ten times its bulk of vital air (which, from a retort, may be expelled by heat). Charcoal is ſaid, by Bergman, to contain ninety-nine parts in one hundred of inflammable matter, or, what I would call, concentrated fire. Here, then, are the two ingredients of inflammability; but what is to ingite them, and let looſe their impriſoned fire? Sulphur; which takes fire more ſuddenly than moſt other ſubſtances, and muſt, therefore, be incorporated with the other two in the moſt intimate manner: powder-mills are for this purpoſe. From inſtantaneous ignition, the fire of the charcoal, and that of the vital air, burſt into a flame, and if unconfined, would occupy 244 times the ſpace they did in the granular ſtate of powder; or diſplace 244 times their bulk of air: or if the powder were confined in a ſpace no larger than its own bulk, it would exert, by the repulſive force of fire it produces, an elaſticity equal to 244 times that of the air. The new chemiſtry accounts for the effects of gunpowder from the rapid, nay inſtantaneous, decompoſition of the nitre, whoſe diſengaged oxygen ignites the ſulphur and charcoal.

Fulminating powder is a mixture of three parts nitre, one of ſulphur, and two of fixt alkali: a powder that, being heated in an open veſſel to melting, explodes with a loud report. Whilſt heating, the nitre and ſulphur melt together, and form a nitrous ſulphur: the acid of the nitre is attracted by the alkali, ſo the vital air of the nitre being intangled by their union, and inflamed by the ſulphur, burſts from both with flame and exploſion.

Phoſphorus. This magazine of fire is formed from the bones of quadrupeds, birds, and fiſhes, long digeſted in vitriolic acid, and which yields microcoſmic ſalt in great abundance. The union of this ſalt, with an equal weight of bruiſed charcoal, affords, by diſtillation, a conſiderable quantity of phoſphorus. This concentration of fire is held ſo looſely by its acid, that a bare expoſure to air (the other ingredient of inflammation) ignites it: hence it is kept for uſe under water. In a heat equal to 60° it burns with a weak flame like ſulphur, and can only be ſeen in the dark; but when expoſed to a heat equal to 160°, or when that heat is produced by rubbing it between the folds of brown paper, it burſts into a vivid and deſtructive flame. Being made into crayons, we can write upon a wall with it, and read the writing in the dark, for every part of the letters produce real flame. Diſſolved in oil, the face may be covered with it, harmleſs, though it has a frightful appearance in the dark. If a few grains of phoſphorus, and an equal quantity of cauſtic alkali, be put into a ſmall glaſs retort (having a long neck), and with theſe a ſmall ſpoonful of water; if the retort be held over a candle, and the end of its neck be juſt immerſed in water, the vapour, as it riſes to the ſurface of the water, burſts into flame, and its ſmoke riſes in phantaſtic rings to the top of the room. A grain of phoſphorus, mixed with the ſame quantity of the oxygenated muriate of pot-aſh, and laid on an anvil, if ſtruck with a hammer will explode with a terrible report. If ignited in vital air, it produces for a few ſeconds the moſt intenſe light.

Many other ſubſtances produce light and fire by colliſion, and ſmell phoſphoric, but have no other qualities in common with it, as phoſphate of lime, tremolite, ſugar, gum-elemi, black jack, and various reſins. Two pieces of borax ſtruck together produce a very ſtrong white light.

The oxygenated muriate of pot-aſh exhibits its fire by friction, and various mixtures: it is a ſalt, and produced by the bleaching gas, and a ſolution of pot-aſh. The bleaching gas conſiſts of

3 parts manganeſe,
8 parts common ſalt,
6 parts vitriolic acid,
12 parts water.

Theſe ingredients are put in a ſtone retort, which is put in a water bath, and its neck luted into the ſide of the room in which is looſely hung the cloth to be bleached. All vegetable colours are ſeized and diſſolved by the gas that iſſues from this retort, and by the liquor which ſubſides when the gas becomes condenſed by the cold of the room. Coloured rags become white as ſnow; as well as paper of a dull colour, &c. Is not this from an affinity between the colours of ſolar light, and the oxygen or vital gas? If this gas be received in a large ſtone bottle, containing a ſtrong ſolution of pot-aſh in water, the alkali will ſeize the acid gas, and the water will become ſtrongly impregnated with a neutral ſalt. When this water is ſlowly evaporated, cryſtals will begin to ſhoot, which being collected and dryed, is the *oxygenated muriate of pot-aſh.* If theſe cryſtals are not white, and pure, they may be diſſolved again in freſh water, and again evaporated.

1. A pinch of this ſalt, mixed with as much ſulphur, and rubbed in a ſtone mortar by a glaſs peſtal, produces ſeveral loud cracks and vivid flaſhes of light. For the friction produces a heat ſuffi-

cient to inflame the ſulphur, which ignites the oxygen gas, and excites its latent fire.

2. If to two or three grains of this muriate, a few drops of ſtrong nitrous acid be added, and while they are uniting, a grain or two of phoſphorus be dropt into them, vivid and beautiful flaſhes of light will iſſue from the mixture for ſeveral minutes.

3. Half a grain of the ſalt, and half a grain of phoſphorus, rubbed in a mortar, produce various loud exploſions.

4. One grain of loaf-ſugar, rubbed with two grains of the ſalt, gives many reports; and if a few drops of ſulphuric or nitrous acid be added, a flame riſes from the mixture to a great height. The oxygen gas of this ſalt being ſo eaſily diſengaged, a little caution is neceſſary in making experiments. Similar reſults to the above take place with charcoal, cinnabar, orpiment, cotton wool, oils of camphor, reſin, &c.

5th. One hundred grains of this ſalt diſtilled in a retort will in the pneumatic apparatus produce ſeventy-five cubic inches of very pure oxygen gas.

The *fiery dragon* of the ancient alchemiſts is another inſtance of the production of ſpontaneous fire. If into an ounce of oil of turpentine, or any eſſential oil, half an ounce of ſtrong nitrous acid (dephlegmated by a few drops of vitriolic acid) be poured; a prodigious flame and thick ſmoke inſtantly ariſes? Eſſential oils contain much latent fire; which being diſlodged by the acid (ſeizing the vegetable part of the oil), ignites with the contiguous air.

Homberg's pyrophorus is made by one part ſugar, and three parts alum, to be melted, ſtirred, and dried on an iron ſhovel, till it becomes a blackiſh coal; when bruiſed, and put into a long-necked bottle, and the bottle into a crucible, filled up with ſand, the crucible being kept red-hot an hour, or till a weak ſulphureous flame has iſſued a quarter of an hour out of the bottle; when leiſurely cooled and corked cloſe in another bottle, if a little of it be poured on brown paper, and breathed upon, it will take fire. Or a more compendious pyrophorus may be made by nearly filling a tobacco-pipe, with two parts calcined alum, one of powdered charcoal, and one of ſalt of tartar. Theſe covered with ſand, and kept half an hour red-hot, when cooled and knocked out will take fire; and if, on paper, wet with oil of turpentine, will burſt into flame.

Fixt alkali keeps fire in a ſtate of combination; breathing on it gives the alkali moiſture, which detaches it from the fire; that fire having motion thus given to it, and conſequently heat, that heat is ſufficient to ignite the maſs.

Pyrophori will not ignite in vacuo, though the containing tube be held in the flame of a candle; but if a little air be let into it, it will inſtantly ignite.

It is ſaid that natural phoſphori, in glow-worms, rotten wood, &c. will ſhine when covered with oil.

Heat is often produced where there is no appearance of combuſtion; and often the appearance of fire, when too weak to produce ſenſible heat: yet is fire never put into motion from a latent ſtate, but it produces ſenſible heat in its extrication.

Mixtures that produce vapour, produce cold in the mixture, and heat in the vapour. If half an ounce of ſal-ammoniac, be put in three ounces of ſulphuric, or marine acid, and a thermometer be put in the liquor, it will fall three inches; while another, held in the vapour, will riſe. Hot coals, thrown into water, cools it for a moment; and the vapour is hot: for latent fire, when put into action, or expelled from bodies, always produces ſenſible heat; and the body is cooled from whence it is expelled.

SECTION III.

SALTS are every thing with a ſharp taſte, and ſoluble in water. *Sea*, or *kitchen ſalt*, is a combination of marine acid and marine alkali. *Luna cornea* is a ſalt formed by the union of ſilver in acid. *Verdigris*, ſalts formed by the ſolution of copper in vinegar; in reality, the ruſt of copper. *Ammoniacal ſalts* are an acid ſaturated with volatile alkali. *Sugar*, an eſſential ſalt, containing vegetable acid, combined with earth and oil. *Pot-aſh*, ſalt found in the aſhes of vegetables. *Nitrous ſalts* are found in old walls, or places abounding with animal and vegetable filth; they are neutral, and produce nitrous acid and fixt vegetable alkali: all ſalts containing acid and alkali are called neutral.

SECTION IV.

EARTHS make up the ſolid part of our globe: and under this name are included rocks, ſtones, mould, &c.; and though theſe are intermixed, and afford innumerable varieties, yet their component parts are but five, viz. lime, ſilex, argil, magneſia, and barytes.

1ſt. *Calcareous earths:* theſe are limeſtone, chalk, marble, ſtalactites (or ſtone icicles), bones of animals *, various fluors, gypſum, or plaſter-ſtone, ſhells of fiſhes, and moſt earths that effervеſce with acids, that fall in white powder when burnt, that will not melt into glaſs by heat, but will melt when mixed with borax, or calces, and aſſiſt the fuſion of lead, copper, and iron. Calcareous earth contains much fixt air, which, as well as the water the earth contained, is expelled by the fire of the lime-kiln: having thus loſt two of its conſtituents, its coheſion is relaxed, and it becomes liable to crumble into a powder fit for mortar, and other purpoſes of building: water facilitates this; for ſlaking lime is but expelling the fire it imbibed and fixt while calcining; ſo the calx receives the water, its old friend, and expels the new. Quick-lime is cauſtic, and diſſolves the fleſh of a defunct in a few hours; this is from its ſtrong attraction of fixt air, which it tears from every kind of body that holds it with leſs affinity than itſelf. Lime-water alſo acquires a cruſt on its ſurface of real lime-ſtone, when expoſed to the air; for there is fixt air in the atmoſphere. Gypſum, or plaſter-of-paris, expoſed to a moderate heat, parts with its water of cryſtallization: when after this it is made into a paſte with warm water, and poured into a mould, for buſts, &c. that water, on cooling, becomes but barely the water of cryſtallization, and the plaſter becomes ſolid in an inſtant.

Calcareous earth is ſuppoſed to be the wearing down of ſhells:

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* The calcareous earth of bones is united with the phoſphoric acid.

from their ſameneſs to the limeſtone maſſes found in all parts of the earth; from the ſhells on living fiſh growing lamina over lamina, till they become fifty or ſixty times as large as the fiſh itſelf; from the fecundity of thoſe fiſhes which throw off this ſtony incruſtation; and the numberleſs generations that are extinct; it is not, indeed, improbable that a conſiderable part of our globe may be covered with their remains.

Calcareous earth being ſuſceptible of extreme diviſion, water, which filters through its rocks, carries off theſe fine parts, and depoſiting them on ſponges, birds'-neſts, moſs, bunches of vegetables, or any matter where the water can ſlowly evaporate, the fibres ſoon become covered with this ſtony incruſtation, which aſſumes the ſhape of the body it covers; and ſuch petrifactions are thought, by the vulgar, to be water tranſmuted into ſtone. Hence the ſtalactites, or icle-ſhaped ſtones, impending from the roofs of caverns; the pyramidal ſpars, &c. Towns and houſes built on a chalky or limeſtone foundation, are obſerved to be leſs liable to infectious or epidemic diſorders, than the inhabitants of any other ſituation.

2d. *Siliceous earths* are flint and precious ſtones, as diamonds, rubies, topaz, opal, agate, quartz, gritſtone, cornelian, jaſper, &c. Many of theſe ſtrike fire with, and even ſcratch ſteel: they do not melt with the ſtrongeſt fire, nor efferveſce with acids; though they are acted upon by fluor ſpar. Alkalis diſſolve it in the moiſt, as well as the dry way, i. e. by melting the earth and alkali together, in a crucible, when it becomes glaſs; or by digeſting them, well bruiſed, with water.

Argillaceous earths are clays that harden in the fire, and are uſed for pottery; clay-marles that effervefce with acids, and moulder in water; boles, ſlates or ſchiſtus, and mica. Alum is a combination of argillaceous earth with vitriolic acid. The moſt obvious characters of this earth are, its adheſion to the tongue, or any wet and ſoft body; its ductility and *kneadability*, by which it can be formed into earthen-ware, bricks, tiles, &c. theſe generally aſſume a reddiſh colour from the iron the earth contains, and a ſolidity from the flinty ſand that vitrifies and holds the parts together while heating. Clays alſo include much water, which, being rarefied in the baking, is apt to crack the clay; but if the water be leiſurely expelled, the clay contracts in baking. On this property is conſtructed a thermometer * for meaſuring the heat of furnaces, by igniting a ſmall cube of baked clay, of known dimenſions, therein, and afterwards meaſuring its contraction.

Magneſian earth. This ſtone is remarkable for a ſoapy, greaſy feel. Steatites are of this genus, of a greeniſh colour, and ſoft enough to be ſcraped with a nail. Soap rock, Spaniſh chalk, Amianthus, Venetian and Muſcovy talc, and aſbeſtos, capable of being ſpun into threads, woven into cloth, and that cloth indeſtructible by fire, are all magneſian. Magneſia may be artificially made by mixing a ſolution of Epſom ſalt with an equal quantity of a ſolution of tartar (oil of tartar) in a glaſs, covering it with the hand, and ſhaking them together, when the magneſia will inſtantly become ſolid in the glaſs: this ſhews, that the water, which kept each in a ſtate of complete ſolution, was but juſt enough for the water of cryſtallization, when the ſalts came together. This earth, as well the others, is capable of a vaſt variety of combinations and effects, which can only be enumerated in works written expreſsly on the

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* Wedgwood's.

ſubject of chemiſtry. After the cryſtallization of nitre, a thick liquor remains, which is called *mother water:* on pouring fixt alkali into this water, there falls down a white earthy precipitate, which, when waſhed and dried, forms the magneſia alba of the ſhops.

Zeolites are harder than calcareous ſtones: they melt eaſily in the fire, with ſwelling and ebullition; and diſſolve with acids, without effervеſcence.

Barytes, or ponderous earth. This ponderous foſſil is above four times the weight of its bulk of water, and is found in the neighbourhood of mines, or veins of metal; it reſembles alum, but is of a ſtriated texture, and is often found in the peculiar figure of a number of ſmall convex lenſes, ſtuck edge-wiſe in a ground. It decrepitates in the fire, melts before the blow-pipe, and fluxes diſſolve it with effervеſcence. This ſtone, when ſtrongly heated, exhibits a bluiſh light in the dark; but to make it a real phoſphorous, it muſt be pulveriſed into powder, kneaded into a paſte with mucilage of gum tragacanth, and formed into thin pieces, like the blade of a knife: theſe pieces are afterwards dried, and then ſtrongly calcined in the midſt of the coals of a furnace; they are then cleared by blowing on them with the bellows. In this ſtate, if they are expoſed to the light for a few minutes, and inſtantly carried into a dark place, they ſhine like glowing coals; even under water! and though in time they become deprived of this property, it is reſtored again by a ſecond heating.

GRANATE is a compound ſtone, often conſiſting of quartz, feld-ſpar, and ſchorl, mixed in a variety of ſhades. The paving ſtones of the ſtreets of London conſiſt of quartz and ſchorl.

SECTION V.

Metals.

PERFECT metals are thoſe that cannot be decompounded, viz. gold, platina, and ſilver. *Imperfect metals* are iron, copper, tin, and lead, which in fire, or ſtrong menſtrua, loſe their metallic properties, become an earth, or calx, but which are revivable into their original metals by phlogiſton, or fire. According to the new principles of chemiſtry, metals, in the act of calcining, imbibe oxygen air from the atmoſphere, and thence become calces, or oxyds: theſe oxyds are reduced (revived) by their oxygen combining with the charcoal of the fatty or inflammable ſubſtances, heated with them, by which carbonic acid gas (fixt air) is formed, and flies off. The metal being thus left free, recovers it metallic or reguline form. Whether this, or the phlogiſtic doctrine, accounts for this intereſting and curious phænomenon moſt rationally, muſt be left to the reader's judgment. That light, or fire, is one of the principal conſtituents of all vegetables; that this fire is capable of being fixt in them by charring in cloſe veſſels; that charcoal holds this inflammable principle by ſtrong affinity, and is not much diſpoſed to part with it, even to the air, except that menſtruum have its attracting reinforced by ſtrong currents from bellows (ſee Optics). Do not the ores of metals imbibe this inflammable principle from the ignited charcoal in a furnace, and thereby become metals? for metals will burn and let out this inflammable principle, like any other combuſtible body. As fire repels itſelf, this principle can be forced out of the metal by great or continued ignition, and the metal again becomes an ore, or, which is the ſame thing, a calx: to this calx I conceive the vitriolic acid to have a ſtronger affinity; and, therefore, when iron is attacked by that acid, diluted, the inflammable principle is diſlodged from the iron, and riſes, with water, in the character of inflammable air, while the acid is ſeizing the calx, and forming with it the ſalt of iron (green copperas). This copperas conſiſts of the calx of iron united with vitriolic acid, and if diſtilled in the common apparatus, fig. 1, Plate XV. yields vital air, and the iron becomes revived, and is found at the bottom of the retort. Iron, alſo, acquiring more ruſt when expoſed in large towns than on mountains, or in the country, from the acidity of ſmoke; that acidity qualifies the calx (ruſt) to produce vital air, when aſſiſted with a little vitriolic acid, in the above apparatus. Do not theſe prove that vital air may be *generated* by acid and fire, as well as attracted from the atmoſphere?

All other metals are liable to nearly the ſame routine of compoſition and decompoſition, and therefore *fixt fire* may be ſaid to be one of their moſt important ingredients.

Metals are all fuſible, though at very different temperatures, and aſſume a cryſtallized figure in cooling; for if a hole be opened in the bottom of the melting-pot, after the ſurface of the metal has become ſolid, and the fluid metal underneath be ſuffered to run out, the under ſurface of the ſolid metal will be curiouſly cryſtallized. This tendency to polarity, if diſturbed, when the metal is paſſing from the fluid to the ſolid ſtate, will make it aſſume a very different appearance and texture to that which takes place when it cools gradually and in quiet; for even water in cryſtallizing, if ſtirred with a ſtick, may become ſolid, but it will not be like ice. Metals in a ſtate of ſolution will grow or ſhoot up the ſides of containing veſſels; but light is neceſſary to the production of this effect.

The affinities of metals to each other are various; ſome will not unite at all, others unite and combine readily; hence the uſe of ſolders. Tin unites pieces of lead; braſs, gold, or ſilver, are ſolders for iron. Tin and copper unite in fuſion, and make braſs, &c.

Metals are moſtly ſoluble in acids, with which, as above, they form ſalts; and act upon the metals as they would do upon any other combuſtible ſubſtance. If an alkali be added to a metallic ſolution, it ſeizes the acid, and the metal, ſo detached, falls to the bottom. But if a metal be put in the ſolution to which the acid has a greater affinity, the acid will forſake its firſt connection, and unite with the ſecond; hence the firſt metal becomes precipitated, and the ſecond diſſolved.

Metals are *opaque* (though leaves of gold $\frac{1}{280000}$ of an inch thick tranſmit green light), hence their great uſe in mirrors; this opacity continues when they are in a ſtate of fuſion. Their *ſpecific gravity* is greater than that of any other kind of body. The *malleability* of metals is one of their moſt uſeful properties; hence they can be extended, flattened, &c. by the hammer, particularly when heated, and made into various inſtruments and utenſils. By their *tenacity* or *ductility* they can be drawn through holes of various diameters into wire of all thickneſſes.

Moſt metals when expoſed to heat and air loſe their luſtre, and become calces or oxyds; and ſome even take fire when expoſed to a ſtrong heat. When theſe calces are covered with powdered charcoal, or any other inflammable matter, in a crucible, and expoſed to a ſtrong heat, they become metals again.

This curious fact is accounted for on the principles of the new chemiſtry in this manner: All metals are ſuppoſed to be ſimple ſubſtances; and that in melting and calcining they do not loſe any thing, but acquire weight by attracting oxygen air from the atmoſphere, and become an oxyd or calx heavier than the metals themſelves. Hence by ſurrounding thoſe oxyds with powdered charcoal, in a retort, as fig. 4, Plate XV. and expoſing it to a ſtrong heat, a quantity of carbonic acid gas comes over into the pneumatic receiver, fig. 1, Plate XV. and the metal is found reſtored within the retort. The calx is ſaid therefore to be a compound ſubſtance, conſiſting of the entire metal united with oxygen; and that the oxygen being expelled by heat, with the gas of the charcoal, theſe together compoſe carbonic gas, and leave the metal behind. To prove the truth of this theory, eight ounces of tin was put in a glaſs retort, fig. 4, Plate XV. with a long ſlender neck: it was heated ſlowly till the tin began to melt, for the purpoſe of expelling ſo much air from it, that when its point was hermetically ſealed, and the retort returned to the fire, it ſhould not burſt. The retort was then accurately weighed, and replaced on the fire; and on the melting of the tin, a pellicle formed on its top, which, gradually increaſed, became a grey powder, that by a little agitation ſunk to the bottom of the liquid metal; but in about three hours this oxydation ſtopt, and no further effect could be produced on the metal. The retort was then weighed, and found preciſely of the ſame weight as before the operation. When the point of the retort was broken the air ruſhed in, and the retort was found ten grains heavier; and the metal and its oxyd being weighed together were found to be ten grains heavier than the eight ounces of tin originally ſubjected to the proceſs. Hence it is concluded, that the increaſe of weight in metals during their calcination is owing to their union with the oxygen part of the air; as it is found that the remainder is azotic, incapable of ſupporting flame or animal life.

Still do I fear there is fallacy in this ſimple and elegant theory:—the gas called carbonic has very different qualities when produced from heated charcoal, from fermenting liquors, from calcareous earths, or the mixture of oxygen and carbonic gaſſes together, yet all theſe go by one name. Any inflammable matter, as well as charcoal, will revive (or reduce) the calces of metals to their metallic ſtate; and the gaſſes ſo produced are very different from that called carbonic in the foregoing theory. Beſides, in this experiment a quantity of air was expelled from the retort by heat, in order when it was hermetically ſealed that it ſhould not burſt:—now this air, ſo expelled, was not weighed; nor was it eaſy to catch it or weigh it; but except it could be proved, that the air ſo expelled bore ſome proportion to the ten grains acquired, it does not follow that the ten grains ſo ruſhing in did not ariſe from the *rarefaction in the retort*; for certainly no allowance is made for that in the experiment.

Though I admire the zeal and accuracy of the truly lamented, and candid Lavoiſier; yet, alas! when we *weigh air*, particularly ſome a little heavier, and ſome much lighter, than our atmoſpheric air, even his accuracy becomes ſuſpicious. But who can be cold enough not to admire the *alacrity* and the *fire* which generally accompanies his reſearches?—it may ſometimes overſhoot the mark, but ſtill it carries with it the genuine marks of *genius* and *invention*.

Gold is unalterable by art; is the heavieſt of all known bodies (except platina); is capable of ſuch expanſion, that a grain may be beat into a leaf of fifty-ſix ſquare inches, and the leaf itſelf be but $\frac{1}{352000}$ part of an inch thick; yet ſilver wire may be gilt, or covered with a ſkin of gold, that is not more than one twelfth of the thickneſs of leaf-gold. Gold bids defiance to the utmoſt power of fire, ſo powerful is its attraction of coheſion; inſomuch that it has been kept for weeks in a glaſs-houſe furnace, and expoſed for hours in the focus of Parker's famous lens, without loſing a grain of its weight. A wire of one tenth of an inch in diameter requires 500 lb. weight to break it. Reduced into powder, it is eaſily attacked by acids; but its metallic nature it is ſaid is in no-wiſe altered. Gold diſſolved by aqua regia, and then precipitated by volatile alkali, waſhed, and ſuffered to dry in a cool place, expoſed to a ſmall degree of heat, explodes with a quickneſs and violence far exceeding gunpowder (ſee Combuſtion). A precipitate of gold from aqua regia is thought by ſome to be a true calx, though moſt metals precipitate it; lead, ſilver, iron, and copper, throw it down in its metallic ſtate. Potable gold is gold taken from its ſolvent by æther and eſſential oils; this liquor evaporated, leaves gold of the utmoſt purity, whoſe ſpecific gravity is near twenty. Guinea gold is alloyed with copper, eleven parts gold to one of copper, ſo as to make its ſpecific gravity only 17,75. Gold is found in its metallic ſtate in moſt parts of the world, in lumps and grains, in the ſands of rivers; ſometimes bedded in earths or ſtones; when theſe are pounded and boiled with mercury, the mercury will unite, or amalgamate, with the gold, and may be eaſily ſeparated from it by diſtillation, as the mercury will riſe with a ſmall degree of heat, and leave the gold.

Silver, the next perfect metal, fuſes in a ſtrong degree of heat (igniting before it melts), and is nearly as ductile as gold, though harder. In leaf-ſilver, it is three times as thick as leaf-gold. The fumes of ſulphur tinge it black; and the ſulphur will, in time, incorporate with its ſurface, and form a coating. The nitrous acid ſeems its natural menſtruum, for it will diſſolve half its weight of ſilver; and the ſolution is very cauſtic, corroding animal ſubſtances, and attacking whatever contains inflammable matter, ſeemingly with an endeavour to become revived. Fulminating ſilver is made by diſſolving a very ſmall quantity of pure ſilver in pale nitrous acid, and precipitating it by the addition of lime-water: this calx, or precipitate, after decanting the water, is to be dried by expoſure to air and light three days: this dried calx being ſtirred, or agitated, in a ſolution of cauſtic volatile alkali, appears a black powder, from which the fluid muſt be decanted, and the powder left to dry in the air. This is the fulminating powder, which, when once obtained, can no more be touched! for the ſmalleſt agitation, any thing dropping into it, even a drop of water, will make it explode with a detonation, and deſtruction of every thing around it, to which a cannon is but as a ſquib! The theory of this terrible effect is much the ſame as that of fulminating gold. Copper will ſeparate ſilver from its union with nitrous acid: if a drop of the ſolution be put on a ſmall copper wire, between two ſmall ſlips of glaſs, in a microſcope, a beautiful foreſt will inſtantly riſe from the copper, which is a precipitation, or cryſtallization, of ſilver, and called the Arbor Dianæ: for nitrous acid having a greater affinity to copper than the ſilver with which it was united, ſeizes the copper, and leaves the ſilver. A more palpable ſilver tree may be produced, by amalgamating four drachms of leaf-ſilver and two drachms of mercury into a paſte. This paſte muſt be diſſolved in four ounces of pure nitrous acid, then diluted with a pint and a half of diſtilled water, and agitated; then preſerved in a bottle, with a ground ſtopple, for uſe. When this preparation is to be uſed, about an ounce of it may be put in a two or three ounce phial, and a ſoft amalgam of ſilver and quickſilver, about the ſize of a pea, dropt into it, and left at reſt. In a few days, ſmall filaments will ſpring out of the ball of amalgam, which will ſhoot into branches, and become a beautiful metallic tree.

Fifteen parts ſilver, and one of copper, melted together, is the ſtandard of the Britiſh coinage. This metal is often found native, though generally mineralized; ſometimes in maſſes, and often diffuſed through ſand, ocre, or lime-ſtone; ſeldom pure: but the ſtones or earth, with which it is united, being pounded, and mixt with mercury, the ſilver will amalgamate with the mercury, and leave the ſtones, or matrix, with which it was united in the mine (for leaf-ſilver will amalgamate on the hand with mercury): now as mercury riſes with ſo ſmall a degree of heat, it is eaſily ſeparated from the ſilver by ſimple diſtillation. This is the manner in which the Spaniards work the mines of Mexico and Potoſi.

A wire of ſilver, one tenth of an inch in diameter, will ſuſtain 270 lb.

Platina, or *little ſilver*, has yet been only found in the gold-mines of Peru and Mexico, and the diſcovery is of recent date: it is found in ſmall angular ſhining grains, like clean ſteel filings, and is the heavieſt body in nature; for when cleared from the iron-looking ſand which generally accompanies it, its ſpecific gravity is twenty-two, and gold is only between nineteen and twenty. It will not melt in the moſt intenſe fire; though it has yielded to the focus of a large burning lens, and become a beautiful white, untarniſhing, and malleable metal. It will weld like iron in intenſe heat; but rejects all acids, except aqua regia, or a mixture of the nitrous and marine acids. When diſſolved in theſe, it is eaſily precipitated by ſal ammoniac; and the ſediment is then fuſible, and capable of management. It alſo unites readily with moſt metals.

Was this extraordinary metal better known to ſociety, probably it would be eſteemed more than gold.

Mercury is always in a fluid ſtate; and will not become a ſolid and malleable metal till cooled to the 39° below 0 of Fahrenheit's thermometer; it is then like ſilver, but more heavy, and a little more bluiſh. Though it is as indeſtructible by fire as gold and ſilver, it riſes with leſs heat than will fuſe any other metal; it is therefore eaſily diſtilled, and ſeparated from the lead with which it is generally adulterated: but expoſed to heat in tall and open veſſels, it readily calcines into a red calx, called red precipitate; which calx may be brought back to its metallic ſtate by a ſtill greater heat: for as a moderate heat expelled its inherent fire, or phlogiſton, from its ſurface (or qualified it to imbibe vital air), ſo when it is confined, a greater heat reſtores fire equal to what it had loſt, and the metal returns to its original ſtate. For though fire drives off the acid from ſulphur, and uniting with it and water making vitriolic acid; that acid, in the character of a gas, and confined in a tube hermetically ſealed, will, by long expoſure in a ſand heat, return to ſulphur: ſhewing, that fire, though obliged to penetrate glaſs, can give to the acid all it wanted, to become what it was at firſt.

Mercury attracts water, and is ſeldom dry enough to be uſed for good barometers, till it has boiled ſeveral minutes in the tubes of thoſe inſtruments. Thermometers ſhould alſo be made with boiled, or diſtilled quickſilver. Nitric acid attacks mercury, and diſſolves it with violence: in this ſolution a conſiderable quantity of nitrous gas is diſengaged: and it is ſaid, that it is neceſſary that the acid ſhould reduce the metal to the ſtate of a calx, or oxyd, before it can act upon it; i. e. that one part of the acid ſhould be employed in *diſpoſing* the metal for ſolution, while the other diſſolves it, in proportion as it is oxydated; and that all metals ſubjected to the action of vitriolic acid, have their ſurfaces firſt oxydated by the acid, and then diſſolved. This double operation, I think, is hard to prove: appearances are in favour of the acid attacking the metal at once. As it is but the calx of mercury that remains in the fluid, after the ſolution of nitrous acid and mercury has ceaſed; if marine acid be added to that fluid, it will ſeize the calx, and fall down with it to the bottom, forming with it a cauſtic ſalt, called *corroſive ſublimate:* but if to a ſolution of metallic mercury the marine acid be added, the compound which falls down is called white precipitate, and is ſimilar to a calomel or mercurius dulcis. As the cauſticity of metallic ſalts ariſes chiefly from the ſtrong tendency which calcined metals have to return to their metallic ſtate; corroſive ſublimate, poſſeſſing this property in an eminent degree, becomes one of the moſt active of mineral poiſons, by tearing from the ſtomach and inteſtines the inflammable principle ſo neceſſary to its reduction or revivification. Cinnabar is ſaid to be the ore of mercury; though cinnabar may be made artificially by a combination of mercury and ſulphur, and is the vermillion of the painters. Mercury is often found native, in ſmall globules in the earth; and as it eaſily amalgamates with gold, ſilver, lead, tin, biſmuth, and zinc, it is alſo found in the character of a paſte united with other metals. It is fourteen times as heavy as its bulk of water; and a cubic foot of it weighs 949 pounds.

Iron is the moſt uſeful to mankind of all metals (except when made into weapons). It is hard, malleable, exceedingly tenacious, ductile, and very light. It requires a moſt intenſe heat to fuſe it, and is therefore brought into ſhape by a leſs heat, and hammering. A wire of $\frac{1}{10}$ inch thick will ſuſtain 450 lb. Its ores are various, ſometimes like large pebbles, ſometimes a ſoft red greaſy pigment; there are whole mountains of iron-ſtone; the magnet is an ore of iron; indeed, there is ſcarcely any thing animal, vegetable, or mineral, that does not contain iron; it is the moſt abundant of all minerals. Theſe ores are prepared for ſmelting, by being broken into ſmall pieces, roaſted, waſhed, and mixed with limeſtone as a flux; baſkets of charcoal and the ore, ſo treated, are alternately thrown down a chimney-like furnace, where a prodigious combuſtion is provoked at the bottom by two pair of enormous bellows, actuated by a large water-wheel. The ore when fluxed falls to the bottom of the furnace, forming a pond of fluid iron, which can be let out into ſand moulds for pigs, pots, &c. This iron, being far from pure, is carried to the forge, where it receives a white heat, and its impurities are beaten out by huge hammers, or ſqueezed out by large rollers; and thus condenſed into bar-iron.

To turn iron into ſteel, the pureſt and moſt malleable is choſen, and bedded in pounded charcoal, in a covered crucible, and kept ſeveral hours in a ſtrong red heat. This is called cementation; which makes the metal more hard, brittle, and fuſible than before; and if ſtrongly ignited afterwards, and plunged in cold water, it becomes fit for edge-tools, &c. The temper of ſteel is judged of by the priſmatic order of colours that appear on its ſurface, as it is ſlowly heating, viz. gold colour, purple, violet, deep blue, yellow, and then red; but if it be urged to exceſs, all the colours are expelled together, which makes the white heat, in which ſtate it can be welded like iron or platina. Steel is heavier than the iron of which it is made. Muſt not this additional weight and additional hardneſs be derived from the charcoal? If charcoal (according to Bergman) be ninety-nine parts in an hundred phlogiſton or fire, is it not this fire that made the ore into iron, and that iron into ſteel? and what is it but this fixt fire that is expelled in the character of inflammable air, when iron is attacked by the vitriolic acid?—is not the inflammable principle driven out by virtue of a more powerful affinity?

This metal ruſts and corrodes when expoſed to the air and moiſture; by which it loſes its fire, and tends to return again to an ore: acid vapours facilitate this decompoſition in large towns; acting upon iron ſomething like the vitriolic acid, expelling the fire, and leaving the calx: for on high mountains, iron ſcarcely ruſts at all. Ruſt may be revived like other calces, by treating it with what contains fire; for being ſteeped in linſeed oil for ſome time, it will obey the magnet, and betray other ſigns of revivification.

Iron ſeems as if it were one of the moſt general products of organization; for it is found in vegetables which are merely ſupported by water: almoſt every mineral ſubſtance of this globe is coloured with it. It is with juſtice conſidered as the very ſoul of the arts. It is the baſis of all black colours. Ocres and Pruſſian blue for painters are derived from iron. It alſo furniſhes the art of medicine with many remedies.

Tin is a white metal, got principally in Cornwall: it is harder than lead; little ſonorous; very malleable, though incapable of being drawn into wire. It can be hammered into leaves but one thouſandth part of an inch in thickneſs, called tin-foil. It melts long before it becomes red-hot; and, in that ſtate, thin plates of clean iron (previouſly rubbed with ſal-ammoniac) dipped in it, become covered with a coat of tin, and are called tin-plates: ſaucepans, kettles, and many other utenſils, are tinned ſomething in the ſame way. In like manner it unites with, and adheres to, other metals, forming with zinc a much harder and leſs malleable compound, called pewter: lead is alſo uſed, which makes the pewter ſofter, and more unwholeſome. With copper, tin unites in the crucible, and the compound is bronze, or bell-metal. Seven parts of biſmuth, five of lead, and three of tin, form an alloy that melts in boiling water. Tin in fuſion ſoon acquires a calx on its ſurface, which being ſkimmed off, freſh calx appears; and theſe calces are one tenth heavier than the tin from whence they are made. Theſe calces are revived into tin again when heated, with powdered charcoal, in the ſame crucible; or the oxydation is prevented when powdered charcoal, or pitch, or greaſe, is thrown over the ſurface of the molten tin, and prevents the acceſs of air. The calx of tin, as well as its finely bruiſed ore, is called putty, and uſed for poliſhing metals, glaſs, &c.

This metal is attacked by all the acids, and holds its fire, or inflammable principle, ſo looſely, that almoſt any of them will diſengage it in the character of gas. If tin-foil be dipt in water, and a ſtrong ſolution of copper in the nitrous acid be poured over it, and then the tin-foil be ſuddenly rolled up, and preſſed together, a violent ebullition will enſue, that will burſt into flame. On examining this effect, when cooled, copper will be found produced, and the tin reduced to a ragged calx. Is not this matter of affinity? Does not the eaſy fuſion of tin, in compariſon of copper, indicate that the baſis of copper holds its inflammable principle with ſtronger affinity than tin? The baſis of the copper (its calx) is only in the ſolution; the copper loſt its fire in the act of diſſolving in the acid, and is, therefore, greedy to ſteal that principle from any thing that contains it: tin holds that principle with a weak attraction; and it is torn from it with ſuch violence by the calx of copper, as not only to produce the uſual heat in ſuch decompoſitions, but ſo as to break out into actual flame. Hence the tin becomes a calx, and the copper is revived. This calx or oxyd of tin, being ſurrounded with powdered charcoal in a crucible, and expoſed a few minutes to a red heat, becomes tin again.

This metal is the lighteſt of all others, being but ſeven times heavier than its bulk of water.

Lead is heavier than ſilver, much ſofter, very flexible, and incapable of being drawing into wire. It melts before it becomes red in the fire, and calcines eaſily, if air paſs over it; firſt turning white, then yellow, and then red: this is minium, or red lead, which is made into wafers; and is a principal ingredient in the fine, denſe, and white glaſs, uſed for achromatic teleſcopes; by refracting the rays of light more powerfully than the alkaline glaſſes. Lead acquires a cruſt by expoſure to the air, which is a partial oxydation that protects the reſt, and therefore, it becomes a laſting cover for houſes. It alſo acquires a ſoft cruſt by being expoſed to the air, and the fumes of vinegar: this calx, when ſcraped from the ſheets of lead (coiled up and expoſed for that purpoſe), is ceruſe, or white lead, uſed in oil painting. Ceruſe diſſolved in concentrated vinegar, affords a cryſtallizable ſalt, called ſugar of lead, from its ſweet taſte, though it is a deadly poiſon. Theſe calces are eaſily revived by giving them back what they loſt in the act of calcination, viz. fire, or any thing that contains it. Hence, if charcoal, oils, fat, or any thing inflammable, be covered in the crucible with the minium, and expoſed to a ſtrong heat, the calx will return to lead. So, if wafers be burnt in a candle, the calx revives, and drops from the wafers in ſmall globules of lead. A ſtrong heat vitrifies the calx of lead into litharge, and a ſtill ſtronger, into glaſs, which will run through the crucible like water through a ſieve. This metal is eleven times and one-half heavier than its bulk of water.

Copper is a reddiſh, hard, ſounding, malleable metal; capable of being reduced into thin leaves, and drawn into ſmall wire. It is procured from ores of various forms and colours; ſome in the ſhape of brook-pebbles; ſome called peacock, and pigeon-neck ores, from their likeneſs to the tail and neck of theſe birds: it is often bedded in hard rocks, or paſſes through them in regular veins, or ſeams. Sometimes a belly of ore (as the miners call it) is found, being a maſs that fills the interior of a mountain. It is firſt roaſted, to drive off the ſulphur with which it is generally united; and broken, ſorted, and ſmelted, in the uſual way. Copper, ſo procured, is heated, and rolled into plates for uſe, or goes to market in ſmall bars. Poliſhed plates of copper expoſed to heat, part with their light, or fire, in priſmatic order; red being forced out where the heat is greateſt, violet where the leaſt, and the other colours playing, as it were, with the vibrations of the fire: copper, however, ſeems to have the ſtrongeſt attachment to green light, and parts with it only by force: the flame of the fuel becomes a beautiful green; and in ſuch a heat as would melt gold or ſilver the copper melts, and burns with whitiſh green flame; but a violent heat will ſublime it in a metallic ſtate. All the acids diſſolve copper, but the nitrous with the greateſt rapidity; much nitrous gas is diſengaged, and the ſolution is of a beautiful blue colour: if a plate of clean iron be immerſed in this ſolution, it becomes inſtantly covered with a ſkin of copper. On this property is founded the profitable mode of precipitating copper from the waters iſſuing from copper mines, which are generally impregnated with the vitriol of copper: bars of iron, placed in ponds of ſuch water, not only become covered themſelves with copper to a conſiderable thickneſs, but precipitate a great quantity, which is taken from the bottom of the ponds, and ſmelted. Is not this alſo matter of affinity? The iron becomes a calx; and the calx of copper becomes a metal. Does not the copper then commit a robbery on the iron? Does it not, by ſtronger affinity, ſteal the inflammable principle of the iron, and become, by that acquiſition, a metal itſelf? while the iron ſo robbed becomes a ſoft calx, full of holes, without the leaſt metallic appearance! Copper becomes oxydated on its ſurface by long expoſure to the air; a coating which protects the reſt: this cover is very hard, and is the patin of the antiquarians, by which they ſometimes fallaciouſly judge of the antiquity of medals and ſtatues. Vinegar, when made to act hot or cold on copper, diſſolves, or rather corrodes, it; this corroſion is the verdigris of commerce. The acid of common culinary vegetables, ſtanding in proper veſſels, performs the ſame effect in a degree; and hence the noxious, and even poiſonous, conſequences that ariſe from the uſe of copper utenſils. The tinning of copper is meant as a protection to victuals, ſo expoſed, from verdigris; but copper is never completely covered by tin, though it appears ſo. This operation is performed by melting the tin in the veſſel to be tinned: this veſſel is firſt well cleaned, and has any weak acid paſſed over its ſurface; the molten tin is then rubbed over its ſurface with rolled-up old rags.

Copper is uſed for large boilers; to ſheath the bottoms of ſhips; and ſtill for kitchen furniture, notwithſtanding the above danger, &c. The ſalt of this metal is call blue vitriol.

Sulphur is found moſt commonly combined with metals, and often in a ſtate of purity in nature. It is inſtantaneouſly combuſtible when it touches an ignited body:—when warmed, it ſends forth a weak odour; in rolls, it cracks by the heat of the hand, and a moderate degree of heat melts it. It is often formed by the decompoſition of animal and vegetable ſubſtances, particularly putrifying vegetables. Expoſed to a conſiderable heat in open veſſels under a ſloping chimney, it ſublimes in the chimney, and is called flowers of ſulphur; when fuſed and poured into moulds it becomes roll-ſulphur. Sulphur cryſtallizes in a beautiful manner, if the bottom of the veſſel in which it is fuſed have an occaſional hole that can be opened when the ſulphur begins to congeal, and to run out into another veſſel. Metals have a ſtrong affinity to ſulphur; and in an hot ſtate, uniting with it, become brittle and fuſible. The imperfect metals are generally found united with it in nature, and it is expelled from them by roaſting before the metal is ſmelted. If mixed with nitre in a retort, and heated, the oxygen of the nitre will unite with the ſulphur, and both riſing by heat in vapour into a leaden ciſtern juſt covered with water, the water imbibes the volatile acid and becomes oil of vitriol, or the ſulphuric acid. If this acid be expoſed to great cold, it concretes in a cryſtalline form; and if combined with the mineral alkali it cryſtalliſes, and is known by the name of Glauber's ſalt.

Arſenic is a metallic calx, of a glittering whiteneſs, like ſugar; has an acrid taſte; and when thrown into the fire, or on an hot iron, ſmells like garlic. This ſubſtance is attached to moſt metals in the mine, is very volatile, and in great abundance; ſo that in working mines, it flies about, and being breathed by the unhappy miners, deſtroys their lungs. Arſenic is too much the inſtrument in the hand of wickedneſs, or imprudence, for anticipating death, by its likeneſs to ſugar.

Cobalt, a ſemi-metal, is of a light grey colour; compact and brittle; difficult of fuſion; and refuſes to amalgamate with quickſilver: it gives a blue colour to glaſs. Arſenic is forced from it by roaſting under long crooked chimneys, in which the arſenic lodges, in ſufficient abundance to ſupply commerce. When the oxyd of cobalt is cleared of its arſenic, it is known by the name of zaffar. This oxyd, fuſed with three parts ſand, and one of pot-aſh, forms blue glaſs. This glaſs pounded, ſifted, and finely ground in mills, forms ſmalt; which is uſed in the preparation of cloths, laces, linens, muſlins, thread, &c.

Biſmuth is a ſemi-metal, of a ſhining yellowiſh-white colour, ſomething like lead: it fuſes with leſs heat than any other metal, except tin. It is found in various ſtrata in the earth, generally combined with ſulphur and arſenic. Nothing more is neceſſary in ſmelting its ore, but to throw it into the fire, and to have a cavity underneath to receive the ſemi-metal. The acids attack biſmuth, and form ſolutions with it, but water precipitates it from all its ſolutions; and the precipitate, when well waſhed, is known by the name of magiſtery of biſmuth, or white paint for the complexion. This pigment is eaſily converted into a metal by ſulphureous vapours, or animal tranſpirations, and loſes its colour. Pomatum, prepared with this magiſtry, turns the hair black.

Antimony is found ſometimes native, in maſſes of ſhining irregular plates; ſometimes in white cryſtallized fibres; but when combined with ſulphur (as is common), it is of a dark bluiſh, or grey colour. Reduced to its reguline ſtate, it is of a ſilvery-white colour; very brittle and ſcaly. Soon after ignition it melts, and as the heat increaſes, it ſublimes in white fumes, which is the calx, or oxyd, of the ſemi-metal, and is uſed to give an hyacinthine colour to glaſs. All the acids diſſolve it. Regulus of antimony pulverized, and mixt with twice its weight of corroſive ſublimate, and then diſtilled, produces a thick unctuous matter in the neck of the retort, called butter of antimony: when water is added to this butter, a white calx falls down, called powder of algaroth, a moſt violent emetic. Equal quantities of antimony and nitre being projected into a red-hot crucible, a calx and alkali is the reſidue, known by the name of diaphoretic antimony: if a greater quantity of nitre be uſed in the projection, vitriolated tartar is found with the other products. This is the baſis of emetic tartar, the principal ingredient in James's powders, and one of the firſt of medicines. Antimonial wine has long been uſed as an emetic. As the calx of antimony may be converted by heat into glaſs, and ſhaped as ſuch, Spaniſh white wine, ſtanding a few hours in ſuch a glaſs, will become a powerful emetic. But this is a very uncertain medicine; for if the wine be more or leſs acid, the weather or room hotter or colder, an uncertain quantity will be diſſolved from the glaſs; and it is, therefore, precarious and dangerous.

Zinc is a ſemi-metal, of a bluiſh brilliant white colour; difficult to be filed, hammered, or otherwiſe reduced to powder, but may be rolled into plates by the preſſure of the flatting-mill. Calamine is the ore of zinc; a ſubſtance like lead-ore, and called by miners black jack. It is pounded, and, with powdered charcoal, put in large pots, and theſe pots in a furnace, like a common oven. Theſe pots have tubes fixed in their bottoms, that paſs through the bottom of the furnace into a veſſel of water. After the tops of the pots are covered, and rammed cloſe with clay, a ſtrong fire is made around them, that fuſes the calamine, which deſcends, in globules of zinc, through the tubes into the water. This is called diſtillation per deſcenſum. Calamine, fuſed with copper, forms braſs; and zinc and copper, melted together, makes pinchbeck, and other gold-like metals. Zinc is attacked by the acids, particularly the nitrous and vitriolic: with the firſt, it produces nitrous gas; with the ſecond, inflammable gas in great abundance. Zinc melts with a ſmall degree of heat; but if the fire be ſtrongly urged, it ſublimes in a calx, like flakes of cotton, flying about the room, and is called philoſophic wool. Dropt in grains, or filings, on a hot poker, it will oxydate in the ſame beautiful manner.

Manganeſe is a calx, and of various colours; in England it is generally black, and of a carious, broken, and rugged figure. It may be made into a metal, mixed with charcoal, and expoſed to a violent heat, like other calces. The appearance of manganeſe is ſo various, that its change of colour by the blow-pipe is almoſt the only teſt by which to know it; the colour coming and going as it alternately becomes a metal or a calx. If a globule of microcoſmic ſalt, with a ſmall portion of manganeſe, be fuſed together upon charcoal, with the blow-pipe, the colour will be a deep red. If the fuſion be continued, by the blue part of the flame of the candle, the colour will diſappear; but may be revived by ſoftening the globule with the upper part of the flame. A little nitre added to the next fuſion (as nitre calcines metals) reſtores the red colour; but inflammable matter will again diſcharge it. We have ſeen, in various inſtances, how charcoal, fat, and other inflammable matters, heated in the crucible with the calces of metals, revive them, and reſtore their metallic form and texture; the above effects are from the ſame cauſe: hence manganeſe is uſed in the glaſs-houſe to deſtroy the colour of glaſs. From the vaſt quantity of vital air produced by heat from this calx (ſee Lecture on Air), ariſes many uſeful and ſurpriſing effects: the bleaching compound has manganeſe for its principal ingredient; the oxygenated muriate of pot-aſh fulminates by the vital air of manganeſe; and if that which is called black wad be dried and kneaded with linſeed oil, in a little time it will become hot, and burſt into flame. Is not this alſo matter of affinity? Does not the vital air of the manganeſe ſolicit the inflammable principle of the oil to an union? for no flame can be produced without the union of theſe two ingredients.

Plumbago, or *blacklead*, is found in many parts of Europe, but moſt perfectly in the mountains of Cumberland. Its uſe in pencils need not be mentioned. It bids defiance to fire; and is, therefore, much uſed in the conſtruction of crucibles. It protects iron from ruſt; and the bright appearance of fire-grates is from the plumbago, with which they are poliſhed.

SECTION VI.

On Vegetable Analyſis.

VEGETABLES and animals are organized bodies, very different from the mineral matters with which we have been hitherto converſant. They unite the powers of mechaniſm to thoſe of chemiſtry, and have an apparatus of tubes and veſſels, by which they elaborate, digeſt, ſeparate, and concoct the various juices that paſs through them, in a ſtyle of the moſt ſublime chemiſtry.

The organs of vegetables are chiefly tubes, calculated to extract and convey fluid matter from the earth and air, principally water; which, obeying capillary attraction in the firſt inſtance, is thence raiſed and elaborated by the contractions and dilatations of ordinary heat and cold to all parts of the vegetable. The interior bark carries up the principal part of terreſtrial and aqueous nutrition; the woody part may be hollow and rotten, while the reſt is in vigour, by the good ſtate of the bark: graſſes, and many plants, alſo, are hollow. Earth, confined in tubs, ſeems undiminiſhed by the growth of plants, though the plant increaſes in weight every month; water, air, and light, ſeem its principal conſtituents: but how theſe are transformed into the mucilage, ſugar, oil, &c. found in analyzing vegetables, we know no more than how bread, rice, fleſh, wine, &c. ſhould form the fleſh and bones of a human creature! The œconomy of animal and vegetable exiſtence is obviouſly ſimilar; and even in matters not very obvious: a thermometer, put in an augre-hole in a tree, will ſhew that the plant in winter is warmer than the atmoſphere by many degrees; that the tree can reſiſt cold by its moiſture not freezing ſo ſoon as the water in its neighbourhood ; that plants ſhut up their leaves and ſleep in the night ; betray irritability, ſenſibility; that a wounded tree, on a froſty day, when the ſun ſhines, will bleed freely on its ſouth ſide, but ſhew no ſigns of ſap on the north, &c. &c. : but to enter into a detail of this curious ſubject, would carry me beyond the plan of this work.

VEGETABLE OILS. *Fat*, or *expreſſed oils*, are ſqueezed, or bruiſed, from the ſeeds of plants, as linſeed, ſweet almonds, nuts, &c. *Eſſential oils* are procured by diſtillation. If an aromatic plant be infuſed in water, or ſpirits, a few hours, and both together committed to the ſtill, a ſpiritus rector of water and oil comes over into a cloſe receiver, that contains the aroma, or odour, of the plant. The eſſential oil often ſwims on the water, and may be ſeparated from it : a ſmall drop of this oil will produce in ſpirit of wine the eſſences called *lavender-water*, *roſe-water*, &c. Fir or pine wood, cut into billets, and burnt in the middle, has a liquor expelled from each end of the billets, which is *tar*. Sometimes this eſſential oil is procured by burning the wood in cloſe ovens, when the tar runs off through channels made for its conveyance. Tar dephlegmated, or boiled, to drive off any water with which it may be combined, becomes *pitch*. Pine, or fir, diſtilled, produces *oil of turpentine*, and an acrid phlegm, or water. This and other eſſential oils inflame with nitrous acid. *Camphor* is a concrete eſſential oil.

SOAP. Fixt alkali of ſoda, made more cauſtic by quicklime, and then put to olive oil, forms a mixture which, in a few days, will acquire a conſiſtency, to be put in moulds, and to be dryed for uſe. An acid will decompoſe the ſoap, by ſeizing the alkali: and hence hard water, i. e. water that contains ſelenite, will not lather with ſoap, becauſe ſelenite contains vitriolic acid.

VEGETABLE SALTS are found in the aſhes of plants. In boiling thoſe aſhes in water, the ſalts become diſſolved by the water; and the refuſe ſwims a-top, or ſinks to the bottom; ſo the impregnated water is eaſily ſeparated: this water evaporated, leaves the ſalts at the bottom of the veſſel. *Soda* is from plants growing on the ſea-coaſt; they are burnt in holes in the earth, ſo as to be in part fuſed, and therefore are in irregular lumps. *Pot-aſh* is from the combuſtion of wood, and from an evaporation of the fluid which exudes from green wood when burnt to charcoal.

Gums are the mucilage of plants, forced through the bark when the ſap is too abundant. We ſee little tears in cherry and plumb trees; and the gum-arabic of commerce is ſuch an exudation from the acacia in Egypt and Arabia. They differ from reſins by not being ſoluble in oil, alcohol, or ſpirit of wine.

Fermentation. Vegetables that abound with the ſaccharine principle, or ſugar, afford by fermentation a ſpirituous liquor. Mucilaginous and glutinous principles are alſo found in vegetables: when mucilage is predominant, the product is acid; and when gluten abounds, ammoniac will be produced in the fermentation. But in all caſes the concourſe of air, water, and heat, is neceſſary to bring about fermentation.

Sap in plants often produces a plethora, breaking out of itſelf, and ſometimes by inciſions. In the ſpring, the ſap in the body of the vegetable preſents only a ſlight alteration in the nutritive juices; but in the ſummer, the whole is elaborated, all is digeſted, and then the ſap poſſeſſes characters very different from thoſe it poſſeſſed in the ſpring.

A rainy ſeaſon oppoſes the developement of the ſaccharine principle, as well as the formation of reſins and aromatics. A dry ſeaſon is unfriendly to mucilage, but otherwiſe to reſins and aromatics. Cold weather is inimical to all theſe, except mucilage, which is the principle of increaſe in the bulk of plants. Hence trees are moſt agreeable in their appearance in cold climates.

Ardent ſpirit, alcohol, or ordinary ſpirits, can only be got from ſaccharine vegetables. Sugar-canes afford rum; grapes, brandy. The refuſe of the ſugar-works, mixed in a pond, or ciſtern with water, go into a ſtate of ſpontaneous fermentation. When that is over, the liquor is diſtilled, and rum is the product. When the ſaccharine principle appears in ripe grapes, they are preſſed, and the juice is received in vats; where, almoſt without ſtum, or yeaſt, it ſoon goes into a ſtate of fermentation. The volume of the fluid increaſes, becomes turbid and oily, and fixt air floats on its ſurface. At the end of ſeveral days, theſe tumultuous motions ceaſe; the woody and impure matters ſink, and the wine becomes clear, and of a red colour. The wine, in this ſtage, grows warm, or otherwiſe the fermentation languiſhes, the ſaccharine and oily matters are not ſufficiently elaborated, and the wine becomes unctuous and ſweet. If rainy ſeaſons produce a want in the ſaccharine body, the wine is weak; and mucilage predominating, cauſes it to become ſour (the ſpirituous fermentation being ſcarcely perceptible). This defect may be remedied by adding ſugar. If the wine be bottled, or put in cloſe veſſels, the gaſſeous principles are retained, and the wine is briſker. Tartar is neceſſary to the vinous fermentation, and it is in proportion to the abundance of the tartar: for wine, deprived of its tartar, ferments no more. Brandy is diſtilled from wine, or rather the lees of wine.

Apples contain a juice, which eaſily ferments, and becomes cyder; pears produce perry: and from both, brandy may be diſtilled. Good wine is nearly one-fifth brandy, of proof ſtrength; and when it is diſtilled with a ſlow fire, or the diſtillation repeated, ſpirit of wine, or alcohol, is produced.

The fruits of ours, and ſimilar cold climates, afford little ſugar; and hence to make wines from currants, gooſeberries, raſpberries, the ſap of the birch, maple, &c. requires much ſugar to be added to the little they naturally contain.

Malt liquor is generally made from barley: this grain contains a tolerable portion of ſugar, which has the glutinous part of the grain taken from it, by ſteeping in water, then laying it on a heap, and exciting the firſt ſtage of vegetation, in ſmall germs, or ſprouts. It is then dried on a kiln, and ground into a coarſe flour, called malt. This malt is infuſed in hot water, in the marſh-tub, and the ſugar and mucilage become diſſolved. This is called the firſt wort; which is again heated, and paſſed a ſecond time ſlowly through the malt. The liquor is then boiled with a certain quantity of hops, which communicate a reſinous bitter. It is then poured into a cooler; and mixed with yeaſt, or an acid leven, to accelerate the vinous fermentation. This ſoon takes place, and continues with warmth and ebullition for many hours; and before it quite ſubſides, the liquor is put in barrels, with the bung open for ſome time before it be cloſed. What then is fermentation? It ſeems to be the means ordained by nature of ſeparating the component parts of animal and vegetable bodies, when their vital functions have ceaſed; and to diſtribute thoſe parts to the general maſs of the elements to which they each belong: ſending earth to earth; water to water; air to air, &c. Moiſture and warmth are neceſſary to this proceſs; for very dry ſubſtances do not eaſily go into a ſtate of fermentation. This curious ſyſtem of diſorganiſation is generally divided into three ſtages: 1ſt, the vinous, or ſpirituous, fermentation; 2d, the acid, or acetous; and, 3d, the putrefactive. Animal bodies ſeem to paſs the two firſt ſtages; and the firſt only takes place in vegetable bodies that contain ſaccharine juices. In theſe, a ſwelling and commotion firſt takes place; in time the groſſer parts ſubſide, and a clear liquor remains. Wines and malt liquors are ſtopt at this ſtage, by being confined in cloſe veſſels: but if left expoſed to the air, the ſpirituous parts evaporate, and they paſs on to the ſecond, or acetous ſtage, by imbibing vital air, and become vinegar. If this ſpontaneous decompoſition is ſuffered to proceed, putrefaction takes place; the vinegar gradually becomes viſcid and foul; an offenſive air is emitted; volatile alkali flies off; and an earthy ſediment ſubſides. The remaining liquor is mere water.

The death of plants is ſimilar to the death of animals; the functions of both ſeem to depend on irritability, or the vital principle. When the vital principle ceaſes to operate, they are no longer ſubject to vital affinity, but to chemical affinity; by which, having loſt their vital principle, they do not periſh, but only loſe their organic ſtructure; and ſoon germinate again into other organiſed bodies.

To prevent fermentation in vegetable or animal ſubſtances, is but to change the proportions of their proximate principles, adding a greater quantity of thoſe principles that will unite with the bodies, and which are not themſelves liable to fermentation. Hence vitriolic acid prevents wine going further into the vinous or acetous ferment. Animal matters are preſerved in ſpirits of wine, common ſalt, or any ſalt. Such animal or vegetable ſubſtances *only* are conſidered as fermentable, which contain oil, or ſugar; for the inteſtine motion of metals and acids is effervеſcence, *not* fermentation.

SECTION VII.

Of Animal Analyſis.

MATTER, when under the dominion of vitality, eludes the analyſing hand of chemiſtry. The vital principle muſt abandon its empire before the menſtruum, or retort, can be uſed. The mineral kingdom is not governed by an internal force; it is ſubject to the action of external powers, ſo invariable, that the effect of fire, water, air, &c. is conſtant, and within the power of calculation. But it is not improbable that the vital principle of animals, or their *irritability*, is continually communicated to the body by the decompoſition of the oxygen part of the air in the lungs, as well as animal heat. Though animal bodies are ſubject to the influence of external bodies, that influence can be ſo modified and varied by the living principle, that the chemiſt muſt look into the living body itſelf for effects, rather than in his laboratory. Yet in that laboratory he has found what airs are beſt to breathe; how to cure thoſe that are noxious; what kind of water and other aliments are moſt conducive to health; and, thence, how to remove the noxious, and ſelect the uſeful. In various diſorders of the animal body, the vital principle ſeems to abandon the government of the parts affected, and to leave the ſolids and fluids to the deſtructive action of external agents; in conſequence of which they become decompoſed; and being deſtitute of the living principle, are ſubject to chemical analyſis. But when this principle abandons the whole body, the ſame cauſes which maintained the functions of it, now begin to act upon the body itſelf. The gaſtric juice is ſeparated by glands placed between the membranes which line the ſtomach, and from thence it is emitted into the ſtomach. This active menſtruum is the chemical ſolvent of food in the ſtomach; it forms it for digeſtion, by the lymphatic and lacteal tubes of the ſtomach and inteſtines: and when it has nothing elſe to act upon, it will attack the ſtomach itſelf, excite the ſenſation of hunger, and even diſſolve the ſtomach after death. Small hollow balls, pierced full of ſmall holes, and filled with fleſh, bread, &c. have been ſwallowed, and ſuffered for a time to lie in the human ſtomach, and when drawn up by a thread attached to them, have been always found empty. This could not be by any mechanic motion of the ſtomach, for the balls were not injured; nor by fermentation, for neither air nor heat was produced; it muſt, therefore, be by the ſolvent power of the gaſtric juice. This juice, however, is different in different animals: when the balls, containing bread, were ſwallowed by a kite, or falcon, they were not diſſolved, though fleſh was; and fleſh was not diſſolved by the duck, or turkey.

Blood is that red fluid which circulates in animals by means of the arteries and veins. It ſupports life, by ſupplying the various organs with the peculiar juices they demand; and is ſaid to derive its red colour from the iron it contains; this iron becoming oxydated by the acid of the oxygen part of breathed air: for if the ſerum and coagulable lymph be carefully waſhed from the red particles, they will be found to contain no iron by the ſtricteſt analyſation, while the red globules will be found to conſiſt entirely of that metal. The blood having diſtributed its oxygen to the parts of the body it comes in contact with in the courſe of its circulation, becomes of a darker colour in the veins on its return to the heart, and is thence propelled by the heart up to the lungs to become renovated with oxygen air: hence drowned or ſtrangled perſons become black for want of that renovation; and it is therefore not remarkable, that if oxygen gas be injected into the lungs of ſuch perſons, the blood even after death will change to red. Blood is generated in the ſtomach, and ſecreted from thence to the heart in the character of milk, where joining the venal blood, they are propelled together up to the lungs, where they imbibe vital air and its heat; become red, as above; and return, in that state, to the left ventricle of the heart. The blood, ſo augmented and purified, is now propelled through the arteries to the extremities of the body; and having diſtributed its heat and nutrition to the various organs in its paſſage, returns by the veins back to the heart a dark-coloured red. To renew this colour from the air in the lungs, and by that decompoſition to ſeize its latent fire, the blood is again forced up to the lungs, &c. As iron is found in analyſing the blood, it has been ſuppoſed that it is made into a red oxyd, or calx, by the vital air imbibed by the blood in the lungs. Air, no doubt, is ſome way the cauſe of its red colour. This humour is, with reaſon, conſidered as the focus of life; nay, by ſome, as being alive itſelf.

Black venal blood expoſed to the air becomes red on its ſurface; but air remaining confined over blood extinguiſhes candles, and becomes carbonic: ſo breathing through lime-water precipitates the lime. Blood in vacuo turns black; but turns red again by letting in the air. Theſe facts prove that the vermillion colour of the blood is owing to the pure air which unites with it.

Reſpiration eſtabliſhes a real focus of heat in the lungs: this heat is in proportion to the magnitude of the lungs (cold animals having but one auricle and one ventricle).

Perſons reſpiring vital air, perceive a gentle heat vivify the lungs, and extend from the breaſt into all parts of the body: in ſhort, the blood abſorbs vital air, even from the atmoſphere, which paſſing from a gaſous ſtate to a fluid one, abandons the fire which held it in ſolution, and in the ſtate of a gas; and which becomes (by accompanying the blood) diffuſed through the whole body, producing *animal heat.* From the greater condenſation of the air in winter, the heat is more conſiderable; and hence northern inhabitants imbibe a heat by reſpiration that counterbalances the cold of their climate: the phænomenon therefore of reſpiration is the ſame as that of combuſtion. See p. 160.

Blood diſtilled on the water-bath, affords phlegm, of a faint ſmell, and which eaſily putrifies; with greater heat, the product is acid, oil, and ammoniac, tempered with fixt air: a ſpongy coal remains in the retort, in which iron and ſea-ſalt are found.

Blood, ſoon after leaving the veins, ſeparates into ſerum, a yellow-greeniſh thin fluid; and craſſamentum, conſiſting of red globules, containing much iron.

Fat is a kind of oil, or butter, made ſolid by an acid, and contained in the cellular membrane. It is a depoſit from the redundancy of food (by the wiſe proviſion of nature), to ſupply the want thereof. Fat, like oil, is not miſcible with water; it forms ſoaps with alkali; and, from the ſtill, produces an oil and an acid phlegm.

Milk is a mixture of oil, lymph, ſerum, and ſalt (detected by diſtillation). The union in this mixture is very weak, therefore eaſily deſtroyed, and the ſeparation produces butter, cheeſe, and whey. Milk, viewed by the aſſiſtance of a microſcope, appears like an infinite number of opaque globules floating in a tranſparent fluid. Milk is ſecreted by peculiar veſſels in the female, for the ſupport of her young; is very ſaccharine in the human ſpecies; milder and ſofter in the cow. When milk is left to ſpontaneous decompoſition, like vegetable ſubſtances, it goes through the vinous, acetous, and putrefactive fermentation, though the firſt is ſcarcely perceptible; yet the Tartars catch it in that ſtate, and convert it into wine. The ſerous and oleaginous parts ſeparate after ſtanding ſome time, the cream riſing to the top, and containing the fat ſubſtance called butter: by agitation, or churning in the air, the fatty particles, ſtriking againſt each other, ſtick together, and ſeparate from the ſerous part with which they were united; which part ſoon turns ſour, and contains a peculiar acid. Milk curdles with any acid; and therefore rennet, which is the infuſion of the ſtomach of a calf in water, coagulates the milk: this property is owing probably to the gaſtric juice of the animal. The curd being collected, and the whey ſqueezed out, it becomes cheeſe.

Eggs very much reſemble milk; the white differs little from the curd of milk; it coagulates with heat without loſing weight; and evidently contains ſulphur, by tinging the ſpoon with which it is eaten. The yolk, being the food of the chick, is an animalized emulſion, well adapted for that purpoſe. Oil, mineral alkali, and ſulphur, are detectable in the eggs of birds.

Fleſh. The animal muſcle is formed of fibres, running lengthwiſe with the body; they are connected together by the cellular membrane, and enveloped in lymph, jelly, and fat. Their analyſis, by diſtillation, affords little information: water, alkaline fluid, empyreumatic oil, ammoniac, and a coal, are the principal product. The digeſtor is, therefore, better than the ſtill; for in a cloſe veſſel, half filled with water, over a ſlow fire, there follows a ſucceſſive diſengagement of the above principles, in the formation of ſoup. The lymph coagulates by the firſt impreſſion of the heat, and appears in ſcum; which is taken off. The gelatinous part then becomes diſengaged, and diſſolving, incorporates with the water. When the water is ſufficiently penetrated by heat, flat round drops ariſe, which, when cold, appear to be fat. As the digeſtion proceeds, the mucous extractive part is ſeparated; the ſoup now aſſumes its colour, and peculiar odour and taſte, and ſalt takes off its inſipidity. By this mode of cookery, the whole nutrition of the meat is preſerved; its digeſtion is more eaſy and nouriſhing than roaſted or boiled meats; for much of their nutrition is evaporated, and ſent up the chimney, and the remainder is left hard, and difficult of digeſtion.

Skin and Bones. The parts of animals, whether membranes, tendons, cartilages, ligaments, or even the ſkin, bones, and horns, contain a mucus that is ſoluble in water, and known by the names of jelly, portable ſoup, glue, ſize, &c. The analyſis of theſe parts is pretty much the ſame as in the laſt article.

SECTION VIII.

Chemical Apparatus.

TO effect the compoſition and decompoſition of bodies; to ſeparate the volatile from the more ſolid parts, &c. various utenſils are required. For though copper and lead, united by fuſion, may be ſeparated by fuſion, becauſe lead will melt firſt, and run from the copper; and notwithſtanding that the mixture of copper and zinc, called braſs, may be decompounded by heat, as the zinc will aſſume the vaporous ſtate firſt; and that quickſilver can be ſeparated from gold, water from clay, &c. by the ſame proceſs; yet ſtill theſe, and thouſands of chemical operations, require apparatus, which we will now endeavour to give an idea of.

Retort, fig. 4, Plate XV. is of glaſs, iron, or earth. Glaſs is the moſt cleanly; is not liable to be corroded; is impervious to air; and ſhews what is going on within. Such a retort, heated in water (called a water-bath), or in ſand, contained in an iron veſſel (called a ſand-heat), is not liable to crack; but ſeldom can ſtand a naked fire.

Alembic, fig. 5, Plate XV. This is a kind of ſtill. The fluids to be ſeparated are put into the log-necked bottle *a*, called a cucurbit; this is luted into the head *d*, which is fixed water-tight in the refrigeratory *m*, kept always full of cold water. To the neck, *e*, of the head, is luted the receiver, or bottle, *c*, called a matrass; theſe, all together, are called an alembic. When a fire is made in *b*, the volatile matter in the cucurbit riſes into the head *d*, and becoming condenſed by the cold water about it, drops into the matrass *c*.

Air Furnace, fig. 6, Plate XV. This furnace depends for its great production of heat on the height of its chimney. For the column of air, of which the chimney is a part, will be light in proportion to that height; and, of courſe, the colder and heavier air will ruſh through the fire with proportional violence, to reſtore an equilibrium; and combuſtion becomes more rapid and intenſe the more air is decompoſed. *a* is the aſh-hole; *c*, the grate; *d*, a ſtone cover, to be taken off to place crucibles in the coals, or cupels in the current of the flame.

Reverberatory Furnace has the fire beaten down by a dome, *a*, fig. 7, Plate XV. on the top of the retort *d*, ſo that the retort becomes heated on all ſides. Sometimes the dome is filled with coals on all ſides of the retort. *c* is the aſh-hole; *g*, the grate; and *m*, luted to the retort, is the receiver.

Woulfe's Apparatus, fig. 8, Plate XV. is a method of diſtilling, by which the vapours that uſually eſcape in the ordinary way are condenſed, or arreſted, in their paſſage through water, or other fluids. *a* is a retort, containing the matter to be diſtilled; *b* is the recipient; *c* is a bottle with three necks, half filled with water;—the firſt neck has a crane tube luted into it, and its other end into one of the necks of *b*; the ſecond neck has a tube open at both ends luted into it; and the third contains a crane that is luted into the other three-necked bottle *d*, which is half filled with an alkaline ley. When all their joints are well luted with lime and white of egg, and the fire put under *a*, the firſt product will riſe into *b*; which, if it be gas, will be forced over the crane *e*, and through the water in *c*, which will arreſt any fixt air that the gas may contain: the gas, on which the water will not operate, will then paſs from *c* through the alkaline ley in *d*, which will arreſt any thing acid contained in the gas; the remainder will then paſs through the crane *g* into an inverted glaſs, as fig. 1, Plate XV. The tubes, *x* and *z*, are only to prevent the burſting of any part of the apparatus, when the gas is generated with too much rapidity.

A blow-pipe added to theſe, will make a gentlemanly apparatus; and even a tobacco-pipe-head is very uſeful for experiments on a ſmall ſcale.

SECTION IX.

Miſcellaneous Obſervations and Experiments in Chemiſtry.

1. IF a ſolution of ſilver, in the nitrous acid, be expoſed to intenſe ſunſhine, the ſilver will revive. Is not this becauſe the calx of ſilver has a ſtronger affinity to light than to the nitrous acid?

2. The ſmelling-bottle may be made with a mixture of quicklime and ſal-ammoniac. *Explanation.* The ſal-ammoniac conſiſts of marine acid (and ſometimes the aërial acid, or fixt air), and the

volatile alkali; which alkali is impriſoned by the acid, and totally without ſmell: but the aërial acid having a greater affinity to quick-lime than the alkali, it becomes forſaken, and mixing with the air, affects the noſe with its pungent ſmell.

3d. Spirits, mixed with water, produce heat; mixt with ſnow, cold; (diſcovered by the thermometer). *Explanation.* Spirits certainly contain more ſpecific fire than water; therefore, on their mixture, water and ſpirits having ſo great an affinity, they unite, and the ſuperabundant fire becomes expelled from the ſpirit, active, and of courſe ſenſible, raiſing the thermometer. But ſnow is ice in a granulated ſtate; and ſpirits help to liquefy it: ice melts by attracting latent fire from all bodies in contact with it (as formerly proved); and, of courſe, draws a portion of its heat from the thermometer immerſed in it, ſinks it, and thereby exhibits cold. It is well known that frozen fleſh-meat thaws ſooner in cold than in warm water: and two cakes of ice in the bottoms of two flat veſſels; if one be juſt covered with boiling water, and the other with cold, of equal quantity, there will be little or no difference in the time of their thawing; for the ice will ſoon aſſimilate the thin ſtratum of hot water to its own temperature. See page 30.

4. Mixtures giving out heat univerſally decreaſe in bulk; and thoſe producing cold, will become larger than the ſum of their two bulks. *Explanation.* The firſt mixture becomes leſs, by loſing a portion of its latent fire, and, of courſe, that repulſive principle that ſet the particles at a diſtance. The ſecond grows bigger by ſtealing fire from contiguous bodies, and thereby producing cold in them.

5. A piece of phoſphorus in a ſolution of ſilver, copper, or other metal, ſoon becomes covered with metallic particles, or revived metal. Is it not the fire, or phlogiſton, of the phoſphorus that has reſtored the calx to its metallic ſtate?

6. If fifteen grains of phoſphorus be melted in a dram of water, and, when cold, if two ounces of vitriolic acid be put to it, beautiful fire-balls will dart from the mixture; but if oil of turpentine be poured upon it, the whole takes fire. *Explanation.* Vitriolic acid and water have ſo ſtrong an affinity, that in uniting, their mutual fire becomes ſo diſengaged, that the heat is ſufficient to ignite the phoſphorus. Strong acids ſeize the baſis of inflammable ſubſtances, and expelling their fire, cauſe heat in ſome, and inflammation in eſſential oils, or other ſubſtances containing much latent fire.

7. *Liquor probatorius* is two ounces of quicklime, and one ounce of orpiment, poured into a pint and a half of boiling water, and left to ſtand thirty-ſix hours: being carefully bottled, a drop or two in a glaſs of white or made wine will detect ſugar of lead, by a cloud falling to the bottom of the glaſs. *Explanation.* Sugar of lead (a deadly poiſon) is a calx of lead, and becomes revived by the ſulphur and arſenic of the orpiment.

8. If a thin ſmall jar, *a*, fig. 9, Plate XV. be half filled with good ether; and the jar *c* half filled with water, and placed under the receiver *z*, on an air-pump; when the air is exhauſted, the ether will boil, and the water be frozen. *Explanation.* Water, and particularly light ſpirits, are kept in a ſtate of fluidity by the weight or preſſure of the atmoſphere; remove the air, and they fly off in

ſteam or gas; but in their flight carry off, and render latent, the fire in the neighbouring bodies. Hence the ebullition of the ether, and the ice of the water.

9th. Cloth dipt in a very diluted ſolution of gold, in aqua regia, and expoſed to the ſun, will appear like cloth of gold. *Explanation.* Light and fire being conceived as the ſame principle, if fire will revive metals, we alſo find that light will do the ſame, particularly when concentrated by a burning lens.

10. Manures act upon land in three ways: 1ſt, Mechanically, by increaſing or diminiſhing the adheſion of the ſoil. 2d, Chemically, by diminiſhing adheſion by putrefaction; by decompoſing metallic or earthy ſalts; by increaſing or diminiſhing the capacity of the ſoil to retain water; by promoting the putrefaction of dead or dying vegetables; and by affording the ſalts and gaſes, which are the pabulum of vegetables. 3d, Phyſiologically, by acting as ſtimuli on the living fibre of the plant; killing, by too ſtrong a ſtimulus, the weak and languid fibre, and exciting the ſtronger to ſtronger action.

11. Dried earth diſtilled, gives inflammable and fixt air in proportion to its fertility.

12. The leaves of any vegetable being boiled in water almoſt to dryneſs, will impregnate that remaining water with nitrous ſalt; ſo that brown paper being ſoaked in it, and then dried, the paper will be found to be very good *quick-match,* will fire gun-powder, and decrepitate in the fire like real nitre. *Explanation.* As the nitrous ſalt is generated in places abounding with filth, lime, dung,

&c. the vegetables of richly manured earth make the ſtrongeſt ley; and therefore that it is probable the manure ſupplies the greateſt part of the nitre of vegetables.

13. Limeſtone, chalk, marble, &c. it is ſaid, will not calcine into lime when incloſed in any thing that keeps the air from them. *Explanation.* Becauſe in a cloſe veſſel their fixt air cannot eſcape, and the cauſticity of lime is from its want of fixt air, and the ſtrong affinitive effort it makes to acquire it from ſubſtances that contain it. Hence, though lime contains no vegetable nutrition, yet, by tearing fixt air from all animal and vegetable ſubſtances that come in its way, theſe ſubſtances become diſſolved, and, mixing with other pabula, form the real nouriſhment of plants.

14. A ſilk handkerchief held in the middle of the flame of an iron furnace, will not burn. *Explanation.* Becauſe air cannot get to the centre; it only has acceſs to the outſide of the flame, and combuſtion will not take place without air.

15. A ſtrong ſolution of Epſom, or Glauber ſalt, in warm water, well corked in a bottle, will remain fluid; but on drawing the cork, the ſalts inſtantly cryſtallize, and become ſolid. *Explanation.* The ſalts and water are both in an expanded ſtate, by heat, when firſt corked; and while no air has acceſs to them, muſt continue ſo: but the inſtant they become liable to the preſſure of the atmoſphere (when the bottle is opened, the water being only ſufficient for the water of cryſtallization), the particles of ſalt are forced within the ſphere of each other's attraction, and inſtantly unite.

16. If ſeveral ſalts are diſſolved together in the ſame water,

when they cryſtallize, each particle will find its own kind, by a ſort of innate polarity; i. e. diſſolve half a pound of blue vitriol, and an equal weight of picked cryſtals of nitre, in ſeparate quantities of boiling water; filter them together, while hot, into a flat bowl: when the water has evaporated a little, the cryſtals will ſhoot, the vitriol all together in blue, and the nitre in white cryſtals, the ſame as before they were diſſolved.

17. Eight parts of biſmuth, five of tin, three of lead, melted together, and a little quickſilver put to them while in fuſion, make a metal that will melt in a handkerchief a few inches above a candle; and expands with heat more than any other metal.

18. That unſeen aroma that tranſpires from plants, and is only ſenſible to the noſe, conſtitutes the volatile character of the eſſential oils, and is of the nature of gas, from its fineneſs and inviſibility. The ſlighteſt heat expels it from plants, and coolneſs condenſes it, rendering it more ſenſible; and hence the odour of plants is moſt ſenſible morning and evening. This aura is ſo ſubtile, that though its emiſſion from wood, leaves, flowers, &c. is continual, there is no ſenſible loſs of weight. Yet it may be extracted and impriſoned, ſo as to conſtitute various eſſences. It is ſoluble in water, alcohol, oils, &c. and the infuſions being diſtilled with a gentle heat, the aroma of lavender, of roſes, of pimento, &c. may be preſerved. This is the union of ſolar light with the fineſt particles of terreſtrial matter; or rather it may be ſaid to be light itſelf, made ſenſible to the noſe as well as to the eyes; for it is in the greateſt abundance in warm climates, and is not produced in cold countries, but where vegetables are ſheltered from cold, and expoſed to the ſun.

19. If powdered charcoal be ſtrewed on ſtrong nitric acid, a little heated, it will take fire. Is not the latent and concentrated fire of the charcoal diſengaged by the acid ſeizing its baſe (the aſhes of charcoal being an alkali)?

20. The *ſemen lycodii*, or witch meal, uſed in theatres to repreſent lightning, is almoſt impoſſible to be wet. This powder, ſtrewed on the ſurface of water, not only ſwims without being wet, but prevents other bodies from being ſo, that plunge into water through it; ſo that a piece of money may be taken from the bottom of a baſon of water without wetting the hand, as the meal deſcends with it. *Explanation.* May not this property ariſe from the great quantity of fire this very inflammable powder contains, which, forming a repulſive atmoſphere round each particle, may puſh the particles of water ſo, as not to touch them?

21. A phial, nearly full of water, was hermetically ſealed, and exactly weighed: the water was then frozen; in which ſtate it was weighed again, and found lighter than when the water was fluid. Was not this by the contraction of the glaſs?

22. Extreme heat, and extreme cold, produce the ſame ſenſation. A Papin's digeſtor burſt in the operator's face, and the ſenſation was that of extreme cold.

23. A green ink, that appears and diſappears by alternate heat and cold, is a ſolution of pounded zaffre in aqua regia, ſtanding twenty-four hours, poured clear off, and mixed with an equal quantity of water: this kept in a phial, with a glaſs ſtopple, is ready to make the leaves of trees, and verdure of the ground, a

ſummer or winter landſcape. For if the picture be held near the fire (like the effect of the ſun), the trees will become covered with leaves, and the ground with graſs: but if taken into the cold, the verdure diſappears, the trees loſe their leaves, and the landſcape is a winter ſcene. In like manner, if the ink is uſed in writing, the paper will ſeem a blank till it is held near the fire, when the writing will appear of a beautiful green: taken into the air, at a diſtance, and again it becomes inviſible: alternately appearing and diſappearing in this way for numberleſs times. *Explanation.* This ink is a ſolution of a green ſalt, that has ſuch an affinity to water, that it can, when dry, attract a ſufficient quantity of water from the air to become fluid, or deliqueſcent: when this water is expelled by heat, the ſalt appears; but it will ſoon acquire from the air a ſufficiency of water to become again a ſolution, and, of courſe, inviſible. Vitriolic acid, mixed with three times its quantity of pure water, is an ink that is inviſible on paper when cool, and becomes black when warmed.

24. Sublimate of mercury, diſſolved in hot water to ſaturation, cryſtallizes as it cools, like flakes of ſnow; and is capable (like the laſt experiment) of perpetual repetition. *Explanation.* All melted ſubſtances may be ſaid to be diſſolved in fire; or as fire repels the particles of matter to a diſtance, it renders the capacity of fluids to receive foreign matter greater: therefore ſolids diſſolve in hot menſtruums eaſier than in cold. But as in this caſe, where the fluid is ſuperſaturated with the ſalt; in cooling the fluid contracts, the ſalts aſſuming the water of cryſtallization, concrete, and deſcend in little aſſemblages.

25. If ſhot and mercury be agitated together, in air, in a bottle,

and the neck be immerſed in water, the water will riſe one-fourth in the bottle; if vital air be in the bottle, the greateſt part of the air will diſappear. *Explanation.* The agitation in air reduces the metals, in a degree, to a calx, or oxyd, which imbibes the vital part of the air.

26. A ſympathetic ink is made by infuſing one ounce of orpiment and two ounces of quicklime in clear water, and in an earthen pot, for twenty-four hours: this is called the firſt water. The writing ink muſt be one fourth of an ounce of the litharge of ſilver, boiled a quarter of an hour in a quart of diſtilled vinegar: writing with this is inviſible; but wiped over with a ſponge wet in the firſt water, the writing appears like that with common ink. To make this ink penetrate through the leaves of a thick book, or even through a brick wall, red lead muſt be diſſolved in the diſtilled vinegar. Writing with this on the title-page of a book, and wetting the laſt page with the firſt water; in an hour this water will penetrate many hundred pages without marking them, and revive the ink on the title-page! *Explanation.* So great is the tendency of a calx to be reduced to its metallic ſtate, that it will attract phlogiſton, or fire, through the moſt ſeemingly impenetrable ſubſtances. In this caſe, the calx of lead becomes revived by the ſulphur and arſenic of the orpiment.

27. In burning a pound of alcohol, more than a pound of water is produced. Let *a b* repreſent an Argand's lamp, fig. 10, Plate XV. with the alcohol in *a*, and the flame under the tube *c*, which tube is continued in a long worm through the refrigeratory *d*, filled with cold water. Now, while ſixteen ounces of alcohol is burnt out of *a*, ſeventeen ounces of water has dropped into the

bottle *e.* *Explanation.* This water, we are told, is generated by the combuſtion of the alcohol. Here again am I under the painful neceſſity of ſetting up my opinion in oppoſition to that of one of the moſt candid, ingenious, and laborious chemiſts perhaps that ever lived. If the cauſe of truth did not fortify me againſt the diffidence I feel in differing from ſo great a name, I ſhould ſink under the preſumption. In ſhort, I think it is the decompoſed water that exiſted previouſly in *that* air conſumed by the lamp. The quantity of heat produced by this lamp, when trimmed with oil, is great; but the heat is intenſe when ſpirit of wine, or alcohol, is uſed; the quantity of air conſumed by this lamp is, therefore, prodigious; and, of courſe, the quantity of water that muſt be detached from it: this decompoſition of water muſt alſo be much increaſed by the great draught of air at the bottom of the tube *c*, which air will be deſtroyed by the flame, while the water it contained will fly up in ſteam, and be condenſed into water again, by the cold worm, down which it deſcends into the bottle *e*. That water is in a ſtate of ſolution in the atmoſphere, is proveable by numberleſs experiments; as well as that air is deſtroyed by combuſtion: is it any way extraordinary that a lamp ſo long, and ſo intenſely heated, ſhould conſume as much air as would hold ſeventeen ounces of water in a ſtate of ſolution?

28. Iron, in a white heat, thruſt into a roll of brimſtone, drops in round, black, ſtriated globules, that are exactly pyrites. *Explanation.* Iron has the ſtrongeſt affinity to the principle of inflammability; and ſulphur contains that principle in great abundance; they form an union; and pyrites conſiſts of ſulphur and iron.

29. While fire ſeparates the particles of bodies, and diminiſhes

their attraction for each other; it proportionably augments their attraction for contiguous bodies, by forcing the particles towards the adjacent body.

30. Ice melts in a heat of 40°, Fahrenheit's thermometer, as faſt as in 212°, being the heat at which water boils: and water grows ſpecifically lighter in cooling from 40° to 32°, the freezing point. See Lecture I.

31. When attraction (in due temperature) prevails in bodies, they are generally in a ſolid ſtate; when fire prevails, they are in a gaſous ſtate: ſo the liquid ſeems to be the medium between the two ſtates.

32. It is probable that all the ſubſtances we call earths are but metallic oxyds, irreducible by any hitherto known proceſs: and even that the German idea, that chalk, kneaded into a ball with linſeed oil, and expoſed to a ſtrong fire, may become a metal, is not groundleſs.

33. To form a curious impending metallic tree, of the revived calx of lead. Diſſolve three or four ounces of the ſugar of lead in a pint of boiling water; ſhake it at intervals, and in the courſe of the day filter it through three or four folds of filtering paper; and if not clear, repeat the filter through freſh paper: put the liquor in a wide-mouthed tall phial, and hang from its cork a piece of zinc, about the ſize of an hazle-nut, ſo that it may be juſt covered with the liquor. In a few days, a beautiful tree will have ſprung downward from the zinc. *Explanation.* Zinc abounds with fire, or the principle of inflammability: it produces, with diluted vitriolic

acid, more inflammable air than any other metal. Sugar of lead is a calx of lead, cauſed by the corroſion of vinegar; this ſalt is diſſolved in diſtilled vinegar, which, when evaporated, leaves the calx to ſhoot into long but weak cryſtals, of a ſweet taſte, and therefore called ſugar of lead. This calx is revived by the inflammable principle of the zinc in ſhining leaves; while the outſide of the zinc becomes itſelf a calx, having loſt its metallic ſplendor and coheſion.

34. To revive limeſtone from its ſtate of quicklime. In burning, the limeſtone loſes two of its conſtituent principles, viz. its water, and its fixt air. The water it will regain by expoſure; for it will attract a ſufficiency from the air about it, and let go its acquired fire. But it wants fixt air to become the ſame ſort of limeſtone it came out of the quarry; this, the human lungs can give to it; for, if a ſpoonful of lime-water be put in a bent ſyphon-like glaſs tube, and the breath blown through it, the fluid will become muddy; the ſtone will be ſeen forming at the bottom of the liquor, which ſtone will efferveſce with acids, and have every other quality it poſſeſſed in the quarry. For a portion of fixt air is thrown out of the lungs at every expiration. Fixt air is ſo powerful an enemy of fire, that if a train of gunpowder leads into the famous Grotto del Cano near Naples, it is inſtantly extinguiſhed. See Grotto.

LECTURE V.

ON THE ATMOSPHERE.

Mechanical Properties of Air.

THE atmoſphere is a thin fluid that ſurrounds our globe on all ſides, like an immenſe ocean. We call it air: and it has the properties of groſſer fluids; by reſiſting the motion of bodies; by ſuſtaining floating bodies; by moving towards thoſe parts that afford it the leaſt reſiſtance; and by excluding other bodies from the place it poſſeſſes. The air is neceſſary not only to the comfort and convenience of man, but even to his very exiſtence, as well as to that of all other animals. Without the atmoſphere neither dew nor rain could moiſten the earth; nor could the ſun impart his light to it. Yet is it principally made up of heterogeneous matter exhaled from the earth; a fluid in which the finer matter of all ſublunary bodies is copiouſly floating. It is a vaſt laboratory, in which nature brings about an immenſe analyſis; ſolutions, precipitations, and combinations. It is a grand receiver, in which all the attenuated and volatilized productions of terreſtrial bodies are contained, mingled, agitated, combined, and ſeparated. It is a chaos, an indeterminate mixture of mineral vapours, animal and vegetable moleculæ, ſeeds, eggs, fire, water, light, meteors, &c. Perhaps it is the fineſt and moſt volatile parts of terreſtrial matter diſſolved in light or fire. About one third of its general maſs is of a purer nature than the reſt, and is called *oxygen* air or gas, and is that part which ſupports animal life and flame, and is the principle of acidity. The other two thirds, when ſeparated from the oxygen part, will neither ſupport life nor flame, is of a noxious nature, and therefore called azotic gas; and is, when united to different baſes, the principle of alkalis. Therefore the atmoſphere is a reſervoir of the acid and alkaline principles, though neither acid nor alkaline itſelf. It is an elaſtic fluid, capable of occupying a larger ſpace than it naturally poſſeſſes; and alſo of being condenſed, or ſqueezed into a leſs ſpace than it naturally poſſeſſes: and hence we find, that its particles repel each other; that this repellency, or elaſtic property, is occaſioned by latent fire, or caloric (in the language of modern chemiſtry), diffuſed through, or rather united with it; and therefore that its particles do not touch each other, nor can be brought into contact by any mechanical force, or the moſt intenſe degree of cold. To produce an idea of this repellency, ſuppoſe fig. 8, Plate XVI. a circle of particles of air, and the particle *e* a particle of fire with repellent rays, puſhing the particles of air to a diſtance. The preſſure of thoſe particles towards one another, by means of their gravity towards the earth, balances the repulſive power of fire in common; but by an acceſſion of active fire (that is, of heat), the power of the particle *e* is increaſed, and the ſurrounding particles of air will be puſhed to a greater diſtance.

1. This is better illuſtrated by a tight bound bladder, half filled with air, held before a fire, when in a few minutes the bladder will be ſo inflated as to burſt.

2. If a bladder, full blown, have great weights laid upon it, it will be found to occupy leſs ſpace than it did before the weights were laid upon it. In the firſt caſe, the repulſive power of fire had the ſuperiority: in the latter caſe, its rays were mechanically preſſed nearer the centre of each particle, and the particles of air brought alſo nearer together.

1. Into the bent tube *o*, fig. 20, Plate XVI. (ſhut at *c* and open at *n*), I pour a little quickſilver (juſt enough to cover its bottom); then will the air in each leg be of the ſame denſity: but if I pour in a little more at *n*, its weight will condenſe, or ſqueeze, the air in the leg *c o* into leſs compaſs: but if I fill the leg *n* up to *s*, the air, which before occupied the ſpace *o c*, will now only occupy the ſpace *r c*; being diminiſhed inverſely as the weight; i. e. diminiſhed as the weight is increaſed: for a double force preſſes the air into half the ſpace; a triple force reduces it into a third of the ſpace. Before we begin to make experiments on the air, it will be neceſſary that the principal engine by which thoſe experiments are made ſhould be explained:—

The Air-pump.—The air-pump is a machine for extracting the air out of veſſels, or receivers (as they are called), and is of various conſtruction. It generally conſiſts of one or two barrels or cylinders of braſs, ſo fixed that piſtons, or air-tight plugs, can work in them by rods paſſing through collars of leathers in the covers of the barrels; theſe rods and piſtons are moved up and down the barrels alternately, by rack-work, or tooth and pinion. The plate of the pump is fixed on a ſtage cloſe to the top of the barrels, and from its centre paſſes a tube to the bottom of the barrels, where there are valves that will ſuffer the air from the receiver to paſs into the barrels, but which ſhut of themſelves when the air endeavours to return. Theſe valves are but a piece of wet bladder or oil-ſkin tied over a ſmall hole, which hole ſhould open upwards that the valves may ſhut by their own weight. There are ſimilar valves to each barrel on the cover of the barrels. If the plate of the pump be very even, a little bees-wax ſmeared on it will prevent any air from getting into the receiver from without; if not, a wet leather is placed on the plate. When an even-bottomed receiver is then placed on the plate, and one of the piſtons drawn from the bottom of its barrel to the top, the air *above* it will be forced through the valve in the cover, and a vacuum will be formed *below* it: to ſupply the vacuum the air in the receiver will (by its elaſtic quality) ruſh into the barrel through the valve at its bottom; the valve will then ſhut, and prevent the return of the air. There are alſo valves in the piſtons, opening upwards; ſo when the piſton deſcends from the top of the barrel, its valve is forced open by the air below, and at the next ſtroke is forced out of the barrel through the valve at its top.—This operation is continued till the air in the receiver becomes too weak to open the valves, and then the exhauſtion is carried as far as the pump is capable, ſhewing that a perfect vacuum is never made by the air-pump. The degree of exhauſtion is ſometimes aſcertained by a barometer tube being ſcrewed into the pump plate, whoſe lower end opens in a baſon of quickſilver; and ſometimes by a ſhort glaſs tube filled with quickſilver, and inverted in a cup of the ſame: this placed under the receiver will indicate the quantity of exhauſtion by the approach of the tube towards emptineſs.

2. I incloſe a bladder, half filled with air, with its neck cloſed, in a receiver, on the plate of an air-pump; it remains flaccid, becauſe the air within and without the bladder is of the ſame denſity: but

when by the pump I draw the air from the receiver, and of courſe from the outſide of the bladder, the air within, aſſuming its ſpring, inflates the bladder, as if full blown. See fig. 2, Plate XVI.

3. If an egg be divided in the middle, and its contents poured out of the thick end; if that ſhell be put under a ſmall receiver on the air-pump, and the air exhauſted, the film, or ſkin, of the ſhell will ſwell, by the expanſion of the air under it, and make the egg appear as if it were become whole.

From theſe cauſes we underſtand why the air grows from a cloſe and denſe ſtate, near the ſurface of the earth, gradually thinner and rarer, till, at a vaſt height, it may be conceived to degenerate almoſt into nothing. Conceive, in fleeces of wool piled upon one another, how the loweſt may be compreſſed by thoſe which lie upon it, how the next fleece will be leſs preſſed, the next leſs than that, &c. &c.; and you will have a tolerably expreſſive picture of the progreſſive thinneſs of the air as we aſcend in it. The difficulty of breathing on high mountains, the oppreſſion of the lungs in the aſcent, and the fall of the quickſilver in the barometer, all indicate its increaſing lightneſs; and that its weight on the ſurface of the earth is occaſioned by the weight and denſity of that air which lies upon it.

1. If any height of the atmoſphere be divided into a number of equal parts, as *s r*, fig. 18, Plate XVI. the preſſure at 1 will be leſs than at *s*; and leſs at 2 than 1, &c.; increaſing in the aſcent by an arithmetical ſeries, as 1, 2, 3, 4, &c. But the deſcent of the quickſilver in the barometer will be in a geometrical ſeries. So that the aſcent into the atmoſphere is arithmetical, while the

fall of the mercury is geometrical: by which is calculated the barometrical method of finding the heights of mountains, &c. Thus at

Miles.			
3½		2	
7		4	
14		16	
21		64	
28		256	
35	above the earth, the air is	1,024	times rarer.
42		4,096	
49		16,384	
56		65,536	
63		262,144	
70		1,048,576	

Upon an average, and without an allowance for a ſmall variation which the difference of temperature makes between the top and bottom of a mountain, about ſixteen fathom is allowed for the fall of one tenth of an inch of the quickſilver in the barometer. So that if the quickſilver deſcends three tenths in aſcending a hill, it will be about forty-eight fathoms in perpendicular height.

This progreſſive rarity of the air ariſes from its gravity being, in ſome meaſure, counteracted by repulſion; for certainly this ocean of air is held faſt to the globe by the power of gravity, as well as the moſt denſe body, as may be proved by numberleſs experiments. It is true, I feel no weight on my hand when I hold it out in this fluid; becauſe the preſſure under and above my hand is equal: but if I lay my hand on a hollow cylinder of glaſs, placed on the plate of an air-pump, and exhauſt the air out of the cylinder, I become immediately conſcious of ſomething that preſſes my hand ſo forcibly to the glaſs, that I cannot releaſe it. The prop is now gone; I have no preſſure under my hand; a column of air, whoſe baſe is the ſize of the cylinder, and whoſe height is about forty-five miles, preſſes down my hand by its weight, and I muſt let in the air under my hand, with a ſtop-cock, before it will be releaſed.

In this experiment the hand undergoes a double ſenſation; beſides being preſſed againſt the top of the glaſs, its fleſh is forced *into* the glaſs, by the ſpring of the air within the hand: for, though air may be ſaid to lie latent, when it is a conſtituent part of our bodies; it inſtantly becomes active, when a vacuum, or a rarity, takes place on any part of the body, and forces out the ſkin, like a blown bladder.

2. I place a ſmall receiver over the hole in the pump-plate; it is removeable at pleaſure, becauſe the maſs of air under it is of the ſame denſity as that which ſurrounds it. I now extract the air, and the receiver becomes ſo fixed to the plate, that I can lift the whole pump by it. What has fixt it?—A column of air, whoſe baſe is the ſize of the bottom of the glaſs, and whoſe height is that of the atmoſphere. This column preſſes the glaſs againſt the plate, and the air under the plate preſſes the plate againſt the glaſs; ſo that they are held together by a mechanical force, as if I preſſed the plate with one hand, and the glaſs with the other.

3. I weigh an empty Florence flaſk, capable of holding a wine quart, on a nice balance; the braſs cap, cemented on its neck, has a valve of wet bladder, opening outward, ſo as to let air out, but to prevent any getting in. This flaſk, ſcrewed on the air-pump, and exhauſted, is then returned to the balance, and will be found to have loſt about ſeventeen grains of its firſt weight; this, then, is the weight of a quart of air on the ſurface of the earth in our lati-

tude: but it is heavier near the poles, and lighter near the equator, agreeable to what was proved in a former Lecture. This experiment is more correctly made by weighing the flaſk in water inſtead of air.

4. I immerſe the neck of an empty bolt-head in a tumblerful of water, and place both under a receiver on the pump-plate. On exhauſting, the air ruſhes from the bolt-head through the water: for when the air in the receiver becomes rarefied, the air in the bolt-head ruſhes through the water, to reſtore an equilibrium, thereby making viſible the expanſive property of the air. But now ten thouſand bubbles of air appear in the water (air that was previouſly diſſolved in the water); for, as the weight of the atmoſphere is taken off from the ſurface of the water by the exhauſtion, there is little obſtruction formed to the repulſion which ſwells ſmall aſſemblages of air ſo as to make them viſible, and riſe with ebullition to the ſurface of the water. This is one proof that water is a menſtruum for air, and diſſolves it. If then the air be let into the receiver, its preſſure on the water will force the greateſt part of the water up into the bolt-head. A bubble of air will probably remain in the top of the bolt-head; but as the water has had moſt of its air extracted, it will, in a few hours, ſeize the bubble in the bolt-head, and abſorb it: another proof that water imbibes air. Fig. 5, Plate XVI.

5. Why are receivers not broken by this preſſure?—Becauſe of their globular figure, which preſents an arch againſt it in every direction. But take a ſquare thin bottle, with a valve opening outwardly on its neck, and place it under a receiver on the pump, and exhauſt the air (for by its ſpring it will come out of the bottle as

well as the receiver); if, then, the air be let in ſuddenly upon the bottle, the valve will ſhut, and the bottle will be broken, with a loud report, by the preſſure of the air on its outſide. Fig. 4, Plate XVI.

6. Having ſhewn that air is contained in a diſſolved ſtate in the pores of water, let us try if we cannot detect water in the pores of air. I ſcrew a ſtop-cock into the pump-plate, *c*, fig. 16, Plate XVI. and, on its other end, ſcrew the braſs plate *d*; on this plate I place the tall receiver *r*, and exhauſt or draw out the air, as before. At the firſt ſtroke of the pump a dim cloud appears in the receiver, and falls in a regular ſhower on the pump-plate. Is not this the water previouſly diſſolved in the air within the receiver, which, having loſt its menſtruum and ſupport, coaleſces and falls? Some are of opinion that this ariſes from the wet leather, generally put between the receiver and the plate: but when the air is excluded by wax, or the even ſurfaces of the glaſs and plate without any interpoſing matter, the precipitation of water ſtill appears. If the ſtop-cock be now ſhut, and unſcrewed from the pump-plate, the glaſs, the plate, and ſtop-cock, will all be fixed together by the preſſure of the atmoſphere. Immerſe the ſtop-cock in a baſon of water, and on opening it, a beautiful fountain will inſtantly play to the top of the receiver, and continue boiling up after the ſmall pipe *e* is covered, till the receiver is nearly full of water. This pleaſing effect is produced by the preſſure of the atmoſphere upon the water in the baſon; for all fluids incline towards that ſide which affords them the leaſt reſiſtance. Rivers run towards the ſea, becauſe they are leſs reſiſted on that ſide than towards their ſource. Water is forced into the tall receiver, becauſe there is nothing in it to reſiſt the preſſure on the water; for we never commit theſe outrages

upon Nature, but ſhe makes ſtrong efforts to reſtore a level or equilibrium. But the grand intention, in this experiment, is to prove the air a menſtruum or diſſolver of water; and that the two fluids mutually imbibe, and enter into combination with, each other. I leave water in a veſſel expoſed to the air: in time it all diſappears. What is gone with it? Believe not that it is annihilated or deſtroyed: nothing in nature is thus deſtroyed, or created; the original particles of matter remain unhurt as they came out of the hands of their great Maker; they are perpetually forming new combinations, uniting, diſſolving, precipitating, and to our groſs ſenſes ſeem to change; but experiment informs us they are immutable. Where then is the water?—Abſorbed, ſoaked up, diſſolved in the air; and, in due time, will be precipitated back on the earth in the character of rain, hail, or ſnow. This ſolution is moſt rapid when water is projected into the air in the character of ſteam; for ſteam is almoſt tangible, iſſuing from the ſpout of a tea-kettle, but is loſt before it has got a yard from it. Where?—In the atmoſphere. For in that attenuated ſtate (its particles ſeparated by fire) it unites with air almoſt inſtantaneouſly. When water, in union with fire, aſſumes the character of vapour, the fire is held in a latent ſtate, quite inſenſible, having loſt its power of burning, and of giving light. But when fire quits its latent ſtate (how long ſoever it may have laid dormant and inſenſible), it always reſumes its proper qualities and character, and affects the ſenſe of feeling and the thermometer, as if it had never been latent. In lakes, rivers, on the ground, &c. evaporation is very ſlow, except aſſiſted by heat; for heat ſeparating the particles of water, or, perhaps, forming them into hollow ſpherules, they become ſpecifically as light as air, riſe into, and chemically unite with it, making one homogeneous fluid. Becauſe evaporation takes place in vacuo, as well as in air, ſome object to this doctrine; for certainly, if a drop of water be allowed to riſe through the quickſilver of a barometer to its top, and be there when the thermometer is even as low as 57, the drop in its evaporation will depreſs the quickſilver half an inch. But how is the doctrine hurt by this? Is the earth at any time ſo devoid of fire, that there is not enough which will attach itſelf to water, nay, even to ice? for ice will evaporate. If fire, in its latent or active ſtate, or in the character of electricity, attaches itſelf to any kind of matter, it repels the particles of that matter, ſo as to make them occupy a larger ſpace; as has been formerly proved. Its union with water forms no exception to this rule, whether it forms it into ſmall globules; carries it up by making it ſpecifically lighter; or becomes the medium by which air and water chemically unite. The particles of water, united with fire, no doubt will repel each other in vacuo as well as in air, ſo as to fill a ſpace devoid of air. That heat increaſes the ſolvent qualities of fluid is evident, from the greater quantity of ſalt, ſugar, tea, &c. that may be diſſolved in hot than in cold water: for fire, in that caſe, is a part of the menſtruum. The ſea is more ſalt in the torrid than in the other zones; for the air will ſeparate freſh water from the ſurface of a ſalt ſea, as water, in diſtillation, will riſe, with a ſmall heat, ſooner than ſalt: hence ſea water comes over freſh in a ſtill, leaving the ſalt behind it. Evaporation is alſo in proportion to the quantity of ſurface: if two veſſels, one twice the ſurface of the other (both being filled with water), be equally expoſed to the air, the larger veſſel will loſe twice the quantity of the other in the ſame time, though the quantity of water in each was equal. Hence woody countries (from quantity of ſurface) produce more rain, than where the woods are cut down. Cultivation increaſing the earth's ſurface by plants, leaves, &c. increaſes alſo the quantity of rain. The mouth of a bell-glaſs, of about twenty ſquare inches, was placed on a new-mown graſs plot, in very dry weather; its inſide was ſoon covered with vapours, which were wiped from it every quarter of an hour, by a piece of muſlin, previouſly weighed. After every wiping, the muſlin was weighed, and ſix grains of water were collected every quarter of an hour. A ſquare yard of coarſe cloth was wet, and then expoſed to a warm ſun; it loſt eight ounces of its weight in an hour. From theſe experiments it is eaſy to reckon that 1600 gallons of water would be raiſed from an acre of ground in twelve hours! Need we be ſurpriſed at the quantity of rain that falls? or at the ſize of the innumerable rivers that carry back that ſurplus to the ſea, that is not wanted for the ſupport of animal and vegetable life, when a cubic foot of atmoſpheric air is found capable of holding twelve grains of water in a ſtate of ſolution?

In the months of March and April, a wet cloth, expoſed to the air, will dry in much leſs time than in the hot weather of July and Auguſt. Why?—By the cold of winter, more rain falls than in ſummer: the air in ſpring is, therefore, leſs ſaturated with water than at any other time of the year; and, of courſe, more ſuſceptible of carrying it off from any thing that contains it. Hence, in looking horizontally through a teleſcope at that time of the year, or on any hot day, the air ſeems in a quivering or undulating motion; but this appearance is not ſeen higher in the atmoſphere. This we conceive to be air and water in the act of uniting; for near the earth they are not ſo intimately mixed but that they break the rays of light differently, and occaſion this tremulous motion [*]. If

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[*] Heated metals in the act of cooling, are always ſurrounded by undulations in the air: this is the caloric, or fire, leaving this metal, and combining with the ſurrounding air.

this heat and undulation take place in the latter part of the day, and the cold, after ſunſet, ſeizes theſe vapours, before they are perfectly diſſolved in the air, then they fall back to the earth, forming miſts and fogs in low grounds; the dews of the morning; and the hoar froſts of winter. Vapour riſing in ſuch microſcopic globules, as ſome repreſent, cannot refract or break the rays of light like a drop of rain; and, therefore, they make no rainbows, but only thoſe undulations.

Vapour made by the breathing of large companies, is condenſed on the ſides of decanters filled with cold water; and on the inſide of glaſs windows in winter, the vapour freezing, ſhews the polarity of ice in tree-like cryſtals, and beautiful foliage.

Stone pavements, walls of houſes, wainſcots, &c. in very cold weather, are deprived of a part of their heat: when warmer weather returns, fire enters theſe bodies, to reſtore an equilibrium of temperature, and leaves the vapours with which it was united on their outſides.

Evaporation is found to be in our climate about four times as much from the vernal to the autumnal equinox, as from the autumnal to the vernal. For heat facilitates all ſolutions. The greater the difference between the temperature of the air and the evaporating ſurface, the greater the evaporation; for if the air be colder than the evaporating ſurface, there will be ſcarcely any evaporation at all.

2. The degree of cold produced by evaporation is much greater when the air is warmer than the evaporating ſurface, than that

cold which is produced when the evaporating ſurface is the warmer of the two; for vapour is dilated in proportion to the electricity it abſorbs; and hence it is coldeſt in an exhauſted receiver, where it dilates moſt. Warm winds, therefore, as the ſirocco, harmatan, &c. are more drying than other winds.

3. Cold is increaſed by currents of air, or winds; for unſaturated air flowing conſtantly over the evaporating ſurface, and coming in contract with it, increaſes evaporation, and, of courſe, cold. Hence calm days are the hotteſt.

4. In winter, the earth at eighteen inches depth is warmer than the air; in ſummer, the air is warmer than the earth at that depth; for the earth is tardy both in receiving heat, and delivering it: at ninety feet it is nearly equal in winter and ſummer. Land imbibes eight or ten degrees more heat than the ſea in ſummer; and is eight or ten degrees colder in winter.

That electricity has a great affinity to water, and aſſiſts its riſe in vapour, is evident from many experiments. Two ſlips of leaf-gold, *c c*, fig. 13, Plate XVI. ſuſpended in a ſmall cylinder of glaſs *d*, with two ſmall ſlips of tin-foil ſtuck to the inſide of the glaſs at *o o*, is called an electrometer: if an hollow cap, *n*, have a little water put in it, when a red-hot coal is dropt into the water, a vapour ariſes, and carries with it a portion of the natural electricity from the cap; the ſlips of leaf gold (by hanging from the cap) alſo, having loſt part of their electricity, ſeparate with negative electricity, and reſtore what they loſt by retouching the ſlips of tin-foil *o o*. See Electricity.

When vapours, by theſe powers, have riſen into the upper and colder regions of the atmoſphere, their parts will be ſtill kept aſunder by the repulſive power of fire or electricity; but when electricity is drawn from its union with this water to the earth, the vapours coaleſce; little aſſemblages of particles get together, and millions of theſe, obſtructing the rays of the ſun, are called clouds. Cold and winds aſſiſt this coaleſcence, and particularly the attraction which theſe little aſſemblages of watery particles have upon one another, by which ſo many of them get together, that every addition now makes the drop become ſpecifically, or bulk for bulk, heavier than the air, and they begin to deſcend as drops of rain; but though ſlowly at firſt, they ſoon accelerate, by attracting ſome, and falling on other drops, increaſing ſo much both in bulk and motion in their deſcent, that a bowl placed on the ground would receive, in a ſhower of rain, almoſt twice the quantity of water that a ſimilar bowl would on a neighbouring tall ſteeple: for water, even in a ſtate of ſolution in the air, is eaſily ſeparated from it by cold; and as the upper region of our atmoſphere is known to be intenſely cold, the drops that deſcend from it muſt be ſo alſo, and by their coldneſs will condenſe the diſſolved vapours in the air as they paſs, and thus alſo increaſe their quantity even in the inſignificant height of a church ſteeple.

Heat has certainly a great influence in ſuſpending vapours in the air; and as we often ſee two currents of air moving in contrary directions, and probably of different temperatures, the warmer current will be cooled by the colder, and conſequently diſpoſe it to part with the vapours it holds in ſolution; hence rain will follow. Sometimes a cloud, juſt in the act of precipitating, will be arreſted by a warm current of air, and diſſolve and diſappear, while we are looking at it.

As the air derives its heat from the earth (as hereafter will be proved), it neceſſarily grows colder and colder the higher we aſcend in it; inſomuch, that aqueous vapours are ſometimes frozen before they become drops. In this caſe, little icicles are formed among the clouds, which, ſticking together, form thoſe flocculent maſſes we call ſnow.

Hail-ſtones are drops of water frozen in their deſcent. In general they are round and ſmall; but attracting, and falling on each other in their deſcent, many ſtick together, and become angular, and ſometimes large enough to break windows, &c.

The diſpoſition of the atmoſphere to retain or part with its vapours, is beſt indicated by the barometer, fig. 12, Plate XVI. This inſtrument is a tube of glaſs, about thirty-four inches long, ſhut at one end (or hermetically ſealed, as it is called), and open at the other; this tube is filled with clean quickſilver, and warmed ſo as to drive out any bubbles of air that may lodge unſeen within the glaſs, and, with a finger on its open end, it muſt be inverted in a baſon of quickſilver; then will the quickſilver fall from the top of the tube a few inches (leaving the ſpace above a perfect vacuum), till it becomes a counterpoiſe to the weight of the air preſſing on the quickſilver in the baſon. The height at which the quickſilver in the tube ſtands above the ſurface of that in the baſon, muſt now be meaſured; perhaps, it may be thirty inches; then muſt a ſcale of three inches be divided into tenths, viz. from twenty-eight to thirty-one, and ſixed on the frame to which the tube and baſon are faſtened: for, in our climate, the quickſilver ſeldom riſes above thirty-one inches above the baſon, or falls lower than twenty-eight inches. When the air is in an heavy and permanent ſtate, ſuſceptible of retaining vapour in a ſtate of ſolution, it preſſes the mercury up, perhaps, to 30 or 30.5. When lighter, and liable to let the vapours coaleſce, it preſſes light on the quickſilver in the baſon, and that in the tube falls, perhaps, to 28.5.; then do we look for rain or wind. But in *our* inſular ſituation, the changes in the weather are ſo frequent and ſudden, that this inſtrument is not ſo indecative as on the continent. In order, however, to make it as prophetical as we can, we ſhould obſerve the top of the quickſilver in the tube; if it appears convex, it is going to riſe; if flat, or hollow, it is going to fall. For it will riſe and fall in the middle, when the attraction of the tube will keep it ſtationary at the ſides; and it is the ſides we generally look at, and fix the indexes to. All fluids flow through themſelves eaſier than through pipes of any kind; even a drain in a field ought to be deeper than it commonly is, that the water may flow over itſelf.

To conſtruct a barometer really indicative of the approaching weather, I made this alteration: In the wheel-barometer, fig. 6. Plate XVI. the tube is bent, and open at its ſhort end. When the tube is filled, the quickſilver will riſe in the ſhort tube to *c*, on which a glaſs ball ſwims, a little heavier than the weight *n*. As the air grows heavier, it will force the mercury down at *c e*, and make the index riſe. As it grows lighter, the quickſilver will riſe at *c*, and depreſs or ſink the index. Now, as the ſcale has two inches to repreſent one, the ball *c* falling half an inch, will produce two inches on the ſcale, and the leaſt ſwell or depreſſion of the quickſilver at *c* will be amply indicated on the ſcale. The ſcale gives a better idea of riſing and falling than a wheel: all the parts are concealed, except the ſcale and index; ſo that it is not liable to be broken: and the indicative part is at the bottom inſtead of the top, and, therefore, more conveniently ſeen. There is a diurnal nutation in the riſe and fall of the quickſilver, that ſhews the barometer to be a little affected by heat and cold: it riſes from ſix to ten in the morning; falling from ten to two in the afternoon: from two to eight it riſes again; and from eight to twelve at night it falls. It riſes again from midnight to ſix in the morning. Theſe effects are not very conſpicuous except in the torrid zone, where the *uſual* riſe and fall are *unuſual*; for the barometer is of little uſe in that zone, remaining almoſt ſtationary all the year. This may, perhaps, be accounted for from the more equal balance that ſubſiſts about the equator between the centripetal and centrifugal forces, than in the other zones of the earth.

7. That it is a variation in the weight of the air that makes the quickſilver riſe and fall in the barometer, we thus prove: We put a plain barometer under a tall receiver, on the air-pump, as fig. 12, Plate XVI. On taking out the air, the quickſilver begins to deſcend, and would all fall into the baſon, if the exhauſtion was complete: but on letting in the air, it riſes to *o*, its firſt ſituation. If the air in the receiver be condenſed, the quickſilver will be forced up to the top of the tube.

The *hygrometer* is alſo an indicative inſtrument for exhibiting the relative moiſture of the atmoſphere; particularly in thoſe ſtates of the air when water is partly diſſolved or diſſolving, or partly precipitating, but in ſuch ſmall aſſemblages of particles that they cannot be ſenſibly felt or ſeen. In this ſtate, thoſe particles are attracted by ſponges, ropes, wood, and other porous bodies, ſwelling ſome, and contracting others; hence a long rope or cord will contract ſo much by moiſture, and expand by dryneſs, that it may be made to act upon an index, ſo as to form a gueſs at the degree of moiſture or dryneſs in the air. A catgut-ſtring is ſtill more ſenſible; and the beard of the wild oat, the moſt ſenſible of any matter known. Bundles of paper dipt in a ſolution of pot-aſh (which powerfully attracts water), if balanced on a ſcale beam will deſcend by moiſture, and riſe by dryneſs, and become a tolerable hygrometer. Slips of whale-bone, made very thin, and acroſs the grain of the bone, makes a very ſenſible hygrometer; and dry deal, or ſpongy mahogany, made into a thin ſlip, acroſs the grain of the wood, about two feet long, and one inch wide, as fig. 19, Plate XVI. contracts by dryneſs, and expands by moiſture: *a d* is the ſlip, faſtened by *a* to a wall, to be expoſed to the air, but not to rain: this ſlip has the index *c g* attached to it at *d*; the index turns on the fulcrum *c*, and points to a ſcale. This is the moſt alive of any of the others; but neither this nor any of the others aſcertain the real quantity of moiſture contained in a given quantity of air: ſo that *dry*, *moiſt*, *wet*, &c. on the ſcale of the hygrometer, are terms at preſent without any definitive meaning. By obſerving this inſtrument, in time, however, as near a gueſs may be formed of approaching weather as by the barometer. Theſe abſorbents ſoaked in water, and dryed to the greateſt poſſible degree with pot-aſh and ſalt of tartar (which abſorb moiſture in an extraordinary degree), have all hitherto failed.

8. Though it is needleſs to exhibit any further proofs of the air's gravity and preſſure, yet its forcing quickſilver through the pores

of wood, is too elegant an experiment to be omitted. A willow ſtick is fixed in the bottom of a ſmall tun-diſh, *c*, fig. 21, Plate XVI. which is placed on the neck of a bottle, ſo as to ſtop it, and prevent any air from getting in; quickſilver is then poured into the diſh, and the air extracted from the bottle; the air's preſſure upon the quickſilver forces it through the pores of the ſtick in thouſands of beautiful ſtreams. A hole is made in the bottom of the bottle for the air to go through, with a knob over it, to prevent the quickſilver from falling into the pump. If the diſh and ſtick be fixed on a ſtop-cock, and the cock be ſcrewed into the top of a tall receiver, and within the receiver there be inverted ſuch a glaſs as *r*, fig. 16, Plate XVI. then may the receiver be exhauſted before the quickſilver is let into it. If now the cock be opened in the dark, the quickſilver will be forced by the preſſure of the air through the pores of the ſtick upon the included and inverted glaſs *r*, and falling down its ſide, excite ſo much electricity as to make for ſeveral minutes the receiver appear filled with flames.

9. We have not yet eſtimated what, or how much, this preſſure is. I take two hemiſpheres, whoſe diameters are three inches, and their area ſeven ſquare inches, fig. 23, Plate XVI. I ſcrew the lower on the pump, and put a wet piece of leather between it and the upper, as fig. 23, then draw out the air from between them, and turn the cock; by this means, they become faſtened together, with a force that is equal to the weight of a column of air whoſe baſe is ſeven ſquare inches, and height forty-five miles. To try how much this force is, I ſcrew the ſtop-cock *c* into the board *d*, and applying the ſteelyard, *r*, and weights, I find it requires upwards of 100 lb. to pull them aſunder! ſo that 100 lb. is the weight of the column of air *G*, ſuppoſed to be forty-five miles in height, and ſeven

inches ſquare at bottom: or about 15 lb. upon one ſquare inch of the earth's ſurface!!

Many of theſe effects may be attributed to what is vulgarly called ſuction: but we deny the exiſtence of any ſuch principle. The preſſure or ſpring of the air accounts for every thing that has the appearance of ſuction.

The above effect may be produced by *condenſed* as well as by common air: for the ſame effects are produced when we make uſe of a condenſed atmoſphere to work againſt common air, as when we make uſe of common air to work againſt a vacuum.—Put the hemiſpheres together in common air, and within a ſtrong glaſs receiver capable of being ſcrewed tight on the forcing ſyringe *y y m*, fig. 12, Plate XVII. and force the air into a receiver, and the hemiſpheres will be as effectually incapable of ſeparation as they were by the preſſure of the common atmoſphere in the laſt experiment.

1. I place a ſmall receiver on the leather of the pump-plate, at a diſtance from the hole from whence the ſuction may be ſuppoſed to proceed, and pour a little water round it. Over this receiver, and over the hole, I place a large receiver, capable of covering both at a time, fig. 3, Plate XVI. On exhauſting, I ſee air come from under the ſmall receiver, by the bubbles it makes in the water, and yet, when I ſhake the pump, I find it is quite looſe; while the larger receiver is ſo fixed to the plate that I can lift the pump by it. Why is not the ſmall receiver faſtened? I *ſuck* the air out of it as well as the large one, yet one is faſt and the other looſe. I now let the air into the large receiver, and the tables are turned; the ſmall one is

fixed, and the large one releaſed. Can this be ſuction? The ſmall receiver was fixed after the ſuction had ceaſed! The fact is, that having taken the air out of both, the large one muſt be fixed, by being expoſed to the preſſure of the outward air; but the ſmall one could not, becauſe there was no air on its outſide to preſs it down: but when the air was let in upon it, and was not able to get under it ſo faſt as it wrapt round it and preſſed it down, it became faſtened by the ſame means that releaſed the other.

2. A boy faſtens the end of a ſtring in the centre of a round piece of wet leather, fig. 10, Plate XVI. he then preſſes the leather on a flat ſtone, and by pulling at the ſtring he lifts the ſtone, thinking it is ſucked up by the leather. No, no, my young Tyro, when you become a little better acquainted with philoſophy, you will find it done by the preſſure of the atmoſphere. You preſs the piece of wet leather to the ſtone, and by pulling at the ſtring, you riſe up the centre of the leather and make a vacuum under it; then will the air endeavour to get into the vacuum, and preſs the edges of the leather againſt the ſtone, and the ſtone againſt the leather, with a force equal to the weight of an ordinary pebble.

3. The inſtrument called a transferrer, explodes the doctrine of ſuction ſtill more effectually. I ſcrew the apparatus, fig. 27, Plate XVI. into the pump-plate, by the ſtop-cock *c*, leaving the cock *d* open, and *e* ſhut. On exhauſting, I faſten the glaſs *g* on its plate, but the receiver *n* is looſe. I then diſengage the whole apparatus from the pump (firſt ſhutting the cocks *c* and *d*), and then can faſten the glaſs *n* on its plate, by opening the cock *e*, and both can be turned down without fear of falling on the floor. Why? The receiver *g* is exhauſted through the channel of the transferrer, and

the cocks *c* and *d*, as effectually, as if it ſtood on the plate of the air-pump: but when this apparatus is diſengaged from the pump, and the receiver *n* is placed on its plate, and a communication is made between the inſides of the two receivers, by opening the cock *e*, the air in *n* ruſhes through the cocks to reſtore an equilibrium with *g*, and becomes, in a degree, exhauſted itſelf; for it divides its air between its exhauſted neighbour *g* and itſelf, and thereby becomes ſubject to the preſſure of the atmoſphere; depoſiting a ſhower of rain, in parting with its air, and becoming fixed to its plate. Could *n* be ſucked down, when all ſuction had ceaſed, and the whole apparatus was removed from the pump?

4. The common houſehold pump aſſiſts in exploding the idea of ſuction; for we prove that water riſes in it by the preſſure of the atmoſphere on the well. Fig. 9, Plate XVI. is a ſucking-pump; *s* is the cylinder of wood, or metal, in which the piſton *r* works. In this piſton there is a trap-door, or valve, opening upward, that will ſuffer water to riſe through it, but when ſhut, will prevent its return. When this piſton is drawn up by the pump-handle, or lever, *t*, as high as *s*, it lifts the column of air that reſts upon it, and would have left a vacuum between *r* and *s*, if the air below did not, by its elaſtic ſpring, endeavour to reſtore an equilibrium; and, by that means, render the air below *r* thinner within the pump than it is without. Hence a difference takes place between the preſſure of the air within the pump, and that without; of courſe, the preſſure on the well being greater than that within the pump, the water will be forced up the tube through the valve *u*, which valve ſhutting by its own weight, will retain the water ſo raiſed, both above and below it. The next ſtroke of the pump-handle will raiſe the water a little higher; the lower valve ſtill retaining the water that has riſen

through it; and ſo on, till the water has riſen to the height of thirty or thirty-two feet, when it ſtops, and no action of the piſton, above it, can raiſe it further. Why?—Becauſe a column of water of thirty, thirty-one, or thirty-two feet high, is equal in weight to a ſimilar column of air of ſorty-five miles high. Is it not the preſſure of the atmoſphere, then, on the well, that forces the water up the pump? and inſtructs us, That a piſton muſt always work within theſe heights, above the ſurface of the water?

But let us try if water will riſe in a pump by ſuction, when there is no air to preſs upon the well. Fig. 1, Plate XVI. *a*, is a pump of the ſame nature as that above; it is ſcrewed tight into the plate *b c*, which covers equally tight the open receiver *d*. While the air has free acceſs to the water, in the cup *o*, if the pump be worked, the water will riſe. But now I place this apparatus upon the pump-plate *e f*, and exhauſt the air from the receiver, and of courſe from off the water: if the pump be then worked with the utmoſt violence, not a drop of water will riſe.

5th. The ſucking of a child ſeems favourable to the doctrine of ſuction. But the rarefaction within the child's mouth, and the preſſure of the air on the nurſe's breaſt, are the cauſes by which the nutritive aliment is forced into the child's mouth: for the human mouth is a natural air-pump. If the tip of the tongue touch the teeth, the cheeks cannot be ſucked in between the teeth; but when the tongue is drawn back, the air is condenſed behind the tongue, and rarefied before it, ſo that the air without, forces in the cheeks between the teeth. The cavity of the mouth may, therefore, be conſidered as the barrel of an air-pump, and the tongue as its piſton. A child, by inſtinct, draws his tongue backwards and forwards, keeping up a continued rarity in the forepart of the mouth, and the preſſure of the air on the breaſt, forces the milk into that rarity. If a cupping-glaſs be ſcrewed to a ſmall ſyringe, and placed on the cheek, and the ſyringe be worked, the fleſh will be forced into the glaſs, and both the glaſs and ſyringe will hang on the cheek: this experiment alſo confutes the doctrine of ſuction.

6th. Breathing may, in ſome meaſure, be ſaid to depend on the preſſure of the atmoſphere. Between the thorax, or cheſt, and the abdomen, or belly, there is a fleſhy flat partition, called the diaphragm, or midriff. By the involuntary action of the *intercoſtal* muſcles, this diaphragm is made to riſe and fall in its centre, thereby alternately increaſing and diminiſhing the cavity of the thorax; and, conſequently, alternately rarefying and condenſing the air among the veſicles of the lungs. When the diaphragm deſcends, the air in the thorax becomes rarefied; and to reſtore an equilibrum, the outward air ruſhes through the mouth and noſe into the lungs, and we are ſaid to *inſpire*. But on the riſe of the diaphragm, the air (as it were) is ſqueezed out, and we are ſaid to *expire*. This operation going on from the moment of our birth, we ceaſe to feel this mechaniſm ſenſibly, long before we are capable of obſerving or reflecting upon it. Hence breathing ſeems to us ſpontaneous; as if no mechaniſm was concerned. The lungs are innumerable bladders, very ſmall and long, impending, as it were, from the windpipe; and ſimilar ramifications of blood veſſels riſe up among them; ſo that the air and blood veſſels intermix, like the fingers of the right hand, put in between the fingers of the left, lengthwiſe: wonderfully convenient for bringing about that purification which the venal blood receives in its paſſage through the lungs. For, after the blood has been forced through the arteries, by the contractions of the heart, and has returned to it again through the veins, and has alſo received an addition from the food, through the lacteals, it makes a digreſſion from the general circulation, up to the lungs, and is rather thick, and of a dark purple colour, occaſioned by its loſs of the caloric, or fire, it derived from the air, and the quantity of fixed air that united itſelf with it in its paſſage through the body. Here the blood undergoes a ſurpriſing change; it almoſt inſtantly becomes of a beautiful red colour, and ſo thin, that, on its return to the heart, it can be forced through the fineſt capillary veſſels. Whence ariſes this change?—Undoubtedly from the air. For, as the air and blood veſſels intermix, and touch with ſuch a quantity of ſurface, they exchange qualities with the utmoſt facility; the blood imbibing the oxygen, or vital part of the air, as well as its latent fire; and delivering to the remaining air the fixed air, and other mephitic gas, which makes the expired air azotic, and unfit to be reſpired again. The blood ſo renewed and purified in the lungs, returns to the heart alive, and being by that muſcle forced again through the arteries, it diſtributes nutrition and heat through every part of the body. Returning again through the veins, it is again ſent by the heart up to the lungs, &c. &c.

The pauſe between every expiration, and the next inſpiration, gives the heated and ejected air time to riſe above the head, and eſcape out of the way of the next inſpiration; ſo it is evident that nature never deſigned us to breathe the ſame air over and over again, as muſt be the caſe when we are incloſed in cloſe and low rooms, double curtains, &c.

Plants expoſed to light emit vital air, and imbibe azote; while man is kept alive by breathing vital air, and emitting azote. It appears then that the animal and vegetable kingdoms labour mutually for each other; ſo that by this admirable reciprocity of ſervices the atmoſphere is repaired, and an equilibrium maintained among its conſtituent parts.

That this is the real œconomy of this part of nature, is provable by many experiments.

1. Blood placed under a bell-glaſs, filled with vital air, will remain florid, and without alteration for many days; but blood expoſed to common air ſoon changes, and becomes putrid.

2. I put the ſhort end of the crooked tube *c*, fig. 28, Plate XVI. into the inverted glaſs *d*, and immerſe both in a large baſon of water; by applying the mouth at *e*, I can breathe the air in the glaſs *d*, without any mixture of outward air. When the air has been half a dozen times in my lungs, I take the crane *c* out of *d*, and put a lighted candle into *d*, which is inſtantly extinguiſhed. If I then put a live bird into it, the bird is ſoon convulſed and dies! for air that extinguiſhes flame is fatal to all animals that breathe air. Therefore a candle ſhould be fixed to the end of a long pole, to try the air in vaults, caverns, places long ſhut up, &c. before they are entered. In the above experiment, the vital air is abſorbed into the blood, and diminiſhed in bulk; its azote and a little fixed air is left in the glaſs; but if to this azote one third of its bulk of oxygen, or vital air, be added, it will become atmoſpheric air again, in which a bird will live, and a candle burn, as in common air before. From this, and other experiments, it appears to many that the general maſs of the atmoſphere conſiſts of two kinds of air, viz. about one third of oxygen gas, or vital air; and two thirds of azote,

or poiſonous air, that will neither ſupport fire nor animal life. Other experiments that favour this hypotheſis are:

1. If a piece of tinder be fixed to the end of a ſmall wire, and, when ignited, be plunged into a two-quart jar filled with vital air, the iron will burn with a vivid flame, and dart out ſulphuric ſparks of a moſt effulgent brightneſs! While this beautiful extrication of light from the iron is going on, the air will be obſerved to diminiſh, and the little globules of oxyd, or rather finery cinder, that drop from the iron, will be found to have increaſed in both bulk and weight above the iron ſo burnt; it is even ſaid that the increaſed weight is exactly equal to the weight of the air which diſappears in the operation: the remaining air in the jar will be found rather worſe than atmoſpheric air, or approaching to azote. This beautiful and ſtriking experiment is generally exhibited to prove that metals change to an oxyd, or calx, only by imbibing the vital air; reducing that air to a ſolid with the oxyd; thereby increaſing the bulk and weight of the oxyd above that of the iron, and alſo proportional to the diminution or loſs of the air. Hence, ſay they, this very vital air may be expelled from the oxyd by heat or a ſtrong acid in the chemico-pneumatic apparatus, and the calx, or oxyd, reduced to the very metal it was before it was ignited, or calcined. That this is fact in regard to lead and quickſilver, may be ſeen from the reduction of theſe calces by heat, concentrated light, or any inflammable ſubſtance, to their original metal. But the pellicles of finery cinder that fall from the burning iron, in the above experiment, are not an oxyd; no air can be got from them by either heat or acid; nor can they be reduced to a metal by any inflammable ſubſtance ignited. Water is a material conſtituent in moſt kinds of air; and in their decompoſition, water is produced.

Fire, gunpowder, and moiſture, will be found in the cavity where it was fired:—inflame equal quantities of inflammable and vital air together, and water will be depoſited; (ſaid to be equal to the weight of the two airs ſo inflamed). Exhauſt a tall receiver on an air-pump, and a ſhower of vapour will be ſeen to deſcend in it. A ſudden degree of cold will precipitate water from the air ſo as to cover the walls, wainſcots, floors, and railing of houſes, with moiſture; ſo, in like manner, is rain, ſnow, and hail, produced. Breathing in a cloſe carriage covers the glaſſes with moiſture; this is the moiſture thrown out of the lungs in the act of breathing, condenſed by the cold on the outſide of the windows: ſo it is in aſſembly rooms; or where a great number of people are in a cloſe room: in ſhort, thouſands of operations, in both nature and art, demonſtrate water to be a conſtituent part of moſt kinds of air—for in their decompoſition water is univerſally exhibited. Even water itſelf, without any other ingredient, may be converted into permanent, elaſtic, and reſpirable air by means of heat; for fill *a b*, fig. 15, Plate XVI. about two thirds with water, and the reſt with quickſilver, then by laying the thumb on the open end *a*, and inverting the tube in the baſon of quickſilver *a c*, the water will fill the part *d b*, and the quickſilver the part *a d*. If, then, a candle be placed leiſurely to heat the water in the inclined tube, it will riſe in ſteam at *b*, and depreſs the quickſilver at *d*; this, for ſome time, will be nothing but common ſteam, convertible by cold back into water; but if this water be kept boiling for the ſpace of an hour, a permanent air will be produced.

Not only from iron can light be let out, but from charcoal or any other combuſtible body ignited in vital air.—The charred bark of wood produces when ſo ignited the moſt beautiful and vivid corruſcations.

What then is the atmoſphere?—A compound of every kind of body capable of a gaſous ſtate by means of heat or fermentation: a receptacle of aqueous vapours; mineral exhalations; of ſteams, ariſing from the perſpiration of whatever enjoys animal or vegetable life, and of their putreſcence when deprived of it; of acids and oils ſeparated from fuel in combuſtion; a chaos of the fine particles of every body with which the air and light have contact; a ſolution of terreſtrial matter in ſolar light, or fire; for the ſun ſeems to have been one of the original parents of our atmoſphere by means of his heat: ſo that, though we ſay that atmoſpheric air conſiſts of oxygen and azote in certain proportions, it cannot be proved to be ſtrictly true; for certainly there is fixed air (or carbonic acid air), inflammable air (or hydrogenous air), and many others; as well as ſteams and exhalations from innumerable ſubſtances that unite with the general maſs of the atmoſphere; all kept in a fluid ſtate by their union with fire or light. It may be ſaid, that the atmoſphere is half its time left without light: yes; but the effects of a fire in a room are long felt after the fire is extinct; and cold increaſes from the ſetting of the ſun till its riſing. Latent fire is put into action, and made ſenſible, by means of active fire. I hold a poker before the fire; it grows hot; not by the fire or heat it imbibes, but by the latent fire it already poſſeſſed being put into action by the repulſive power of the fire before which I held it. I lay fuel upon a fire; it will not burn till it is heated; that is, till its inherent, its natural fire, is put in motion by the repulſive fire of external heat. I rub a piece of phoſphorus between the folds of brown paper before it will ignite; becauſe the friction puts its latent or fixed fire into motion, and aſſiſts its diſpoſition to unite with the air, to which it has the moſt natural affinity, and thence to break out into flame: even a candle will not light till its ſnuff be heated. Light, therefore, conſidered as diluted fire, lies dormant in darkneſs (without loſing much of its repulſive property), for night air is not found to be much more denſe than day air, becauſe of the ſhort abſence of the ſun, which by its ſtream of light ſoon puts the ſtagnant fluid into motion, and produces all the effects of viſion, reflection, refraction, heat, &c. in the day. The repulſive power of light, and its identity to that of fire, I hope will be ſufficiently proved in my Optical Lecture, as well as that the fluidity of the air is owing to its repulſive power; and though ſuſpended light may have its power of affecting the optic nerve in the abſence of a luminous body, it ſtill exiſts even in darkneſs, and wants only a luminous body to put it in motion, and make it ſenſible light.

Oxygen gas.—That the earth is the other natural parent of the atmoſphere is evident from the immenſe number of animal, vegetable, and mineral ſubſtances which produce air by means of heat, or by ſtrong affinities. I bruiſe the mineral ſubſtance called mangane ſe, and put it in a ſtone or iron retort, *a*, fig. 7, Plate XVI. which being flat, may be thruſt in between the bars of a kitchen fire; its mouth *b* is ground to fit the metal pipe *c*, and *c* is united to the cloſe but flexible pipe of leather *d*; to *d* is joined the long metal pipe *e*, which may either come over the top or through the water-bath or veſſel *g*, into *h*, the bottle that is to receive the air. When a briſk fire is made round the retort *a*, a little common air in the interſtices of the manganeſe will come over firſt, and may be ſuffered to eſcape; but, after fifteen or twenty diſcharges from the pipe *e* through the water in *g*, the bottle *h* full of water may be inverted on the end of the pipe *c*, when the oxygen gas, or dephlogiſticated air, will riſe into it with great rapidity, and ſoon expel all the water that was in it; this bottle removed, another and another may ſupply its place; ſo that ten or twelve quarts of pure vital air may be expelled from one pint of bruiſed mangane$ſe$. Was not this air, in a ſolid ſtate, a part of the manganeſe before it was expoſed to fire? Did fire any thing more to it than repulſe it from the baſes with which it was united, and unite with it itſelf? and by that union keep it in a permanent gaſous ſtate? Does not the ſun by his heat perform the ſame thing every moment, and on every part of the calciform parts of the earth expoſed to his heat? and is not a conſiderable portion of the earth's ſurface (and that to a conſiderable depth) in a calciform ſtate? Scarcely can we lay hold of an handful of earth, but, by applying an acid to it, with a due portion of heat, vital air may be produced. It is true, that chalk, limeſtone, marble, ſhells of fiſhes, and all calcareous earths, produce in their union with fire an air poiſonous to the lungs of animals that breathe. It has been called fixed air, aërial acid, and now carbonic acid gas, as being ſuppoſed to be derived from charcoal. Why chalk, the dung of animals, &c. ſhould be called charcoal, is beyond my comprehenſion. That charcoal, heated in a retort, does produce the ſame ſort of air is certain; ſo do vegetables in the vinous ſtate of fermentation, and many other matters that have no other quality in common with charcoal.

Thus nitre, acted upon by either ſolar or culinary heat, produces oxygen gas. This ſalt is ſpread more or leſs over the ſurface of the whole habitable earth, and is produced from a mixture of animal and vegetable earths and juices. The proceſs of nature in producing pure air from this ſalt is ſucceſsfully imitated by diſtillation, i. e. by the ſame proceſs that was uſed with manganeſe. No ſubſtance we know in nature contains ſo much fire in a combined ſtate as oxygen gas. Metals and combuſtible bodies when duly heated unite their inherent fire with the oxygen gas of the air, and light and heat are diſengaged. Combuſtion is therefore ſimilar to reſpiration: a candle will burn but a ſhort time confined under a cloſe veſſel, and the air in which it burned will be found to have loſt its oxygen part, nothing remaining but azotic gas and fixt air. So an animal that breathes air, being ſhut up in a cloſe veſſel, will live but a ſhort time; the air will have loſt its oxygen, and only azotic and fixt gas will be found to remain. Reſpiration is therefore an operation in which oxygen gas is continually paſſing from the gaſous to the concrete ſtate, and at every inſpiration giving out in the lungs the heat or latent fire it held in combination: and hence the heat of different ſpecies of animals depends on the quantity of oxygen gas they decompoſe in the act of breathing. *See Blood.*

How very important and various are the operations of this principle in the grand ſcheme of nature! When combined with earthy ſubſtances it renders them combuſtible; and duly excited, is ready to give out its *light* and *heat*, for the uſe and performance of many of the moſt neceſſary, comfortable, and pleaſurable conveniences of human life. The arts are alſo indebted to it for the different and various acids; for oxygen is the principle of acidity in all bodies. When taken into the lungs it cauſes animal heat and irritability.

Carbonic acid gas, or fixt air.—The effect of ſolar heat on chalk, limeſtone, and other calcareous earths, is *fixed air*, or carbonic acid air. This effect may be ſmelt in chalk-pits on an hot day; and taſted, after agitating this air in a bottle half filled with water; the water acquiring in a degree the acidulous taſte of Pyrmont water. The carbonic air that forms a thin ſtratum on the floor of the Grotto del Cano (that ſuffocates dogs and other low animals immerſed in it), is another inſtance of the natural production of this part of our atmoſphere. But as this air is ſpecifically heavier than the general maſs *, it ſeparates from it in the night, or when the air is quiet and free from wind, and falling down on the earth, becomes elaborated into the food of plants, being a principal ingredient in the cauſes of their growth. Hence ariſes the fertilizing quality of lime, of ſhells, and marles; and the rapid growth of plants, whoſe roots are treated with fixed air. That fixed air is a conſtituent part of vegetables is evident from the quantity they throw out when put into a ſtate of fermentation; ſo that, like putrefaction, which diſorganizes ſome bodies to feed others, fixed air is diſcharged from the decompoſing body, and becomes the food and part of the ſubſtance of the growing plant. If wood be charred in cloſe veſſels, ſo that the air cannot eſcape, the air becomes fixed in the charcoal; but if this charcoal be diſtilled in the apparatus, fig. 7, Plate XVI. that fixed air becomes volatilized by the heat, and comes over an aërial acid, a carbonic or fixed air; the coal delivering back to the atmoſphere the very particles of air it imbibed when a living plant. It is true, that ſolar heat is not equal to that which is neceſſary to produce thoſe airs in the laboratory; but when we take into the account the continued action of the ſun,

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* It is a curious experiment, to put a lighted candle in the bottom of a glaſs jar; and from another jar, to pour the fixt air it contains into the firſt jar; the fixt air, by its ſuperior weight to common air, ſinks to the bottom, and extinguiſhes the candle.——It alſo kills animals immerſed in it.

and ſee the ſteams and exhalations which he enables the air to extract from the earth, we may ſay, that our boaſted effects produced in the laboratory, are but the humble imitations of what that great chemiſt, the Sun, has been producing every day ſince the beginning of time!

Charcoal is one of the moſt powerful antiſeptics: it preſerves water from putrefaction; it preſerves meat; ſweetens rancid oil; and is an excellent tooth-powder.

This fixt air or carbonic acid may be alſo formed by burning charcoal in ſuch a quantity of oxygen gas as is exactly ſufficient for its combuſtion; in that caſe, both the gas and charcoal diſappear, and a new gas (juſt the weight of the oxygen and charcoal) takes place, which is fixt air. Water abſorbs more than its bulk of fixt air.

Hydrogen gas.—Beſides this heavy air which ſeparates from, and ſinks to the bottom of, the atmoſphere, there is alſo a part that is lighter than the reſt, and no doubt forms a ſtratum in the upper regions of the atmoſphere; this, as well as the heavy air, will be mixed with the general maſs by the winds, and other commotions in the air, and may be brought within the ſphere of attraction of bodies to which it has an affinity, and unite with them. This has been called phlogiſton, inflammable air, and now hydrogen gas, as being ſuppoſed to be one of the ingredients that compoſe water. It is produced by nature in various decompoſitions, both animal, vegetable, and mineral. In the animal kingdom, when that ſubtil chemiſt, putrefaction, takes in pieces an organized body, ſending earth to earth, water to water, air to air, &c. the inflammable principle of the body is alſo let looſe; and if it meets with a warm ſtill air will often ignite ſpontaneouſly, as may be ſeen in hot climates over a recent ſhallow grave, on a ſtill evening, like a pillar of ignited particles.

The air which ſwells the bodies of dead animals is a compound of inflammable and fixt air, which, when diſcharged, each returns to its proper function; fixt air to the earth, and the roots of plants, whilſt the inflammable part aſcends to the upper regions, often forming meteors, falling ſtars; and ſometimes, in the very act of diſcharge from rotten animal and vegetable ſubſtances, ignites in the character of Will-o'-th'-Wiſp. In muddy ponds, near great towns, inflammable air may be procured in great abundance, by filling a bell-glaſs in the pond with water, and inverting it in the water; if then the mud be ſtirred with a ſtick beneath it, bubbles of inflammable air will riſe from the mud, and fill the glaſs; this air being expoſed to a candle, will take fire, and often explode. The living fraxinella throws off ſo great a portion of this inflammable matter, that the air around it will take fire from a candle, like the air in a coal-pit. Metals decompoſing by expoſure to air, or water, throw off great quantities of this inflammable matter, loſing thereby the metallic ſplendor, and becoming calces, or oxyds. So iron and zinc, expoſed to a violent fire, throw out inflammable air; and if iron filings are expoſed in the focus of a burning-glaſs, they will leap about, and ſhew that aëriform matter is expelling from them by the heat. We are inſtructed that metals become calces by imbibing vital air, becauſe many calces are heavier than the metals of which they are made: this is true in calces made by art, but not of thoſe made by nature; for the ruſt of iron is not ſo heavy as the iron from whence it became a calx; nor is that of expoſed lead, copper, tin, &c.; nor will thoſe calces produce vital air, like the calces of lead, mercury, &c. made by a ſtream of air paſſing over them while in a ſtate of fuſion; in this proceſs the air is diminiſhed, its purer part diſappears, and the reſt will neither ſupport animal life, nor flame: no doubt the calx has ſeized the pure part, by means of a ſuperior affinity; aſſuming a concrete form, adding weight; and is ready to give back this concrete matter in an aëriform ſtate, when forced by the power of fire, or a ſtill ſtronger affinity, as has been ſhewn. May not the particles of this kind of air have a ſtronger affinity to fire, or light, than any other; by which its particles are puſhed to a greater diſtance from each other than in common air? and thereby derive its great levity, its elaſticity, and inflammability? but alone it extinguiſhes flame; and will not explode without a mixture of vital or common air: for vital air contains within itſelf the principle of fire, as well as inflammable air, but holds it with a weaker affinity; hence this fire emerges upon its union with the body in combuſtion; and by extricating fire from inflammable air with ſome difficulty, it burſts out with exploſion.

Inflammable air (or *hydrogen gas)* is produced in great abundance by means of the apparatus, fig. 22, Plate XVI. *a b c* is an horſe-ſhoe tube of caſt-iron, with the ends *a* and *c* made to receive ground ſtopples; the tube is filled with iron wire, or bits of clean iron, and then thruſt in between the bars of a hot fire: the cup and tube *d a* is luted into the end *a*, and ſo is the tube into the end *c*. The cup *d* is now filled with water, which is prevented from falling into the great tube *a b c* by the conical valve *e:* but this valve can be opened more or leſs by the ſcrew *s*, ſo as to let the water drop leiſurely into the hot tube *a b c*. Inflammable air (thirteen times lighter than common air) will now come over with violence into the inverted bottle *q*, which muſt be replaced with diſpatch by other bottles filled with water. When the proceſs is over, the tube and the iron within it will be found to have acquired weight: the wire, in particular; which will appear like Ethiop's mineral, or the ſcales around a blackſmith's anvil.

Mr. Lavoiſier having made this experiment the foundation of a new theory in chemiſtry, it is neceſſary to obſerve, that he weighed the tube, the wire, and the water; and he ſecured the water from evaporation prior to the proceſs: when it was over, he weighed the tube, the wire, and the air produced, and found they had acquired juſt the ſame weight which the water had loſt. This he conſidered as analytically decompoſing the water, or taking it in pieces, as it were; and in order ſynthetically to recompoſe it, or put it together again, he took the air produced, and as much oxygen gas, or vital air, as he ſuppoſed might be produced from the oxydated wire and tube, and ſetting fire to them by an electrical ſpark in a ſtrong cloſe veſſel (after being exhauſted), he found, when the flame had expired, a quantity of water depoſited exactly equal in weight to that which was expended in the firſt experiment. This experiment was contrived and executed with the utmoſt preciſion, caution, and addreſs, and with inſtruments in which neither accuracy nor expence was wanting; yet I confeſs that the concluſion drawn from it, viz. that water is compoſed of hydrogen and oxygen gas, is by no means clear to me. In the firſt place he takes as much oxygen gas as he *ſuppoſes* might be produced from the oxyd of iron and wire to burn with the hydrogen gas: now this is ſuppoſition; he did not make the oxygen gas from the individual oxydated iron; but what is more, it is impoſſible to make it from iron ſo oxydated, for that I have tried over and over again, as well as many abler chemiſts. Beſides, to weigh air accurately, and particularly air thirteen times lighter than common air, even with the nice and expenſive apparatus of Mr. Lavoiſier, I think next to impoſſible. That water has the appearance of being produced by the burning of theſe two airs, there is no doubt; nay, that its weight may approximate to the weight of the two airs ſo burnt, is alſo very probable; for water is detectable in all kinds of air, and doubtleſs is its heavieſt part; therefore, when any air is decompoſed, water is produced. It is well known, that a mixture of highly concentrated ſulphuric acid (vitriolic acid) and water, will produce a heat greater than that of boiling water; for if in two equal quantities of theſe a thin glaſs veſſel be put filled with water, the water will ſoon boil. Now when inflammable air is produced from iron filings and diluted vitriolic acid in the common way, this heat is produced: for if that heat be ſuffered to cool before the iron is put to the mixture, the efferveſcence will be very weak, ſhewing how neceſſary fire is in the production of inflammable air. Into the ſtrong bottle *a*, fig. 30, Plate XVI. we put a quantity of nails, iron filings, or bits of clean iron, and juſt cover them with water; if then, about one fourth of the quantity of water of ſtrong vitriolic acid be poured into the bottle, a violent ebullition will begin: the crane tube *b* (having one end a ground ſtopple for the bottle *a*) is now fixed in the bottle *a*, and its other end under the bottle *c* (full of water, and inverted in the baſon of water *d*); bubbles of inflammable air now riſe rapidly to the top of the bottle *c*, and diſplace the water, ſoon filling the bottle. If the thumb be then placed on the mouth of the bottle, while under water, the bottle may be taken out; and if its mouth be held to a candle, a ſmall exploſion will take place there: if then it be ſtopt, and again addreſſed to the candle a ſecond, a third, and even a dozen exploſions will ſucceed one another; for the air will not inflame but in contact, or in mixture with common air, ſo the exploſions take only place at the mouth of the bottle. But if a bottle be only half filled with inflammable air, and the other half with common air, it will explode all at once, and moiſture will be found depoſited in the bottle. But to make this air an ingredient in aërial gunpowder, it muſt be mixed with an equal quantity of oxygen gas (vital air), in a ſtrong bottle; otherwiſe, when held to the candle, the exploſion and expanſion are ſo great, as to ſhiver a weak bottle to pieces. Piſtols are often charged with theſe two airs, in the pneumatic tube; and ſometimes, when common air is uſed, by placing the piſtol over the effervefcent bottle, as fig. 24, Plate XVI. The piſtol *a*, being naturally full of common air, has its mouth placed looſe on that of the bottle; but the inflammable air being lighter will mount up to the top of the piſtol, and diſplace an equal quantity of the common air: if now a cork be put in the mouth of a piſtol, and the knob *c* approach the excited conductor of an electrical machine, the cork will be diſcharged with almoſt the velocity of a muſket ball, and with a loud report: for the knob is ſcrewed on the end of a wire *c d*; which wire being cemented in the inſide of a thick tube of glaſs, it becomes inſulated from the metal of which the piſtol is formed; this tube is alſo cemented into the neck of the piſtol; ſo that when the knob approaches the electrical machine, a ſpark takes place at *d*, which ſets fire to the inflammable and common air in the piſtol, and diſcharges the cork. Many other amuſing experiments are made by inflammable air, as may be ſeen in the lecture on electricity. But the intention here is to endeavour to account for the appearance of water on the inflammation of theſe two airs. The ſulphuric acid (vitriolic acid) will not attack iron alone, it muſt be highly diluted with water, before inflammable air will be diſcharged from the iron (for ſtill I do conceive that it is the iron which produces the greateſt part of this air): water inſtantly ſeizes the acid, which becomes decompoſed, and its latent fire is let looſe, to the air or other ſurrounding bodies;—and the water and acid are diminiſhed in their volume, that is, they form a penetration with each other, that makes their ſum leſs than their two parts ſeparate, occaſioned by the loſs of heat. It is alſo proved, that when this gas is let through water in the veſſels *c* and *d*, fig. 30, Plate XVI. that the ſame quantity weighs one eighth more than when it is let through theſe veſſels filled with quickſilver; proving its ſtrong affinity to water, and that it holds it in ſolution.—Now as this experiment is generally made through water, and as a quantity of water riſes with the gas in ſteam, from the exceſſive heat produced by the water and acid, as above, is it not more than probable that, in decompoſing this air by firing it, the water in ſolution, and that in the character of ſteam, become diſengaged, and return to the elementary ſtate of ſimple water, and even to weigh as much as the air, when a pint of it, ſo mixed, weighs no more than 1$\frac{1}{7}$ grain? With the moſt profound reſpect for the valuable names I differ from, I do think water an element, notwithſtanding its apparent compoſition and decompoſition. Is it not the general cement of all other matters? exiſting (though without the character of water) in ſalts, cryſtals, animals, plants, &c. and in this kind of combination giving hardneſs and tranſparency to bodies? and uniting the particles of ſtones, plaſters, lutes, &c.? Is there any ſubſtance in nature in which we do not find it combined more or leſs? From even metals it can be expelled viſibly by heat. It is united with all acids whether in a liquid or ſaline form; and, therefore, in the decompoſition of bodies, water is univerſally diſengaged. If then, as has been proved by experiment, fig. 15, Plate XVI. water may be converted into a permanent elaſtic gas by fire; and that every ſubſtance in nature is alſo capable of producing air when duly penetrated with caloric (fire); is it natural to ſuppoſe that a fluid which conſtitutes more than half the ſurface of our globe ſhould be formed by the ſlow proceſs of burning oxygen and hydrogen gas together? Is it not more conſiſtent with the wiſdom and frugality of nature, that theſe gaſes ſhould be formed from water? But theſe gaſes cannot be formed from water alone; other ſubſtances, containing inflammable matter, muſt be united with water in the proceſs, or no hydrogen gas will be produced. With a blunt ſteel point, a hole may be beat through at *a* in the bottle *c*, fig. 14, Plate XVI. If then the wire *d* and its knob be cemented in that hole, the bottle may be filled with water, and inverted in the baſon of water *g*. Take a wire, with a knob at each end *y*, and bend it ſo that one knob may be half an inch from the knob already in the bottle; if the knob *y* be made to communicate with the outſide of a Leyden jar, and the knob *d*, with its inſide, diſcharges of electricity through the water will generate inflammable air; *which can be only an union of electric fire and water:* proving, that if fire can be forced into union with water, the compound will be inflammable air. Iron contains inflammable matter, and will burn like a ſtick in vital air. Both in the experiment fig. 22, and that fig. 30, Plate XVI. the iron loſt its inflammable principle, and became ruſt, or a finery cinder; it is, therefore, more than ſuppoſititious that the iron ſupplied the inflammable principle to the gas, and the electricity to the water. This inflammable principle has been called the phlogiſton of metals; I take the liberty of calling it *light*, in the firſt inſtance, and *fire* in the ſecond, when it becomes condenſed, incorporated with, and a conſtituent part of, a body. That light forms the greateſt part of all plants, I hope will be ſufficiently proved in the Optical Lecture; that wood in charring has this light concentrated into fixt fire; and that (according to Bergman, ninety-nine parts in 100 of charcoal is fixt fire, or phlogiſton) the ore of iron muſt be fluxed in a furnace with charcoal before it becomes a metal. Does not the metal then derive its ſplendor, its texture, its ſtrength, &c. from the inflammable part of the charcoal? and is it not ready to give back the inflammable principle in its original ſtate of light when ignited in vital air? and alſo when an acid tears it from its baſis in the formation of inflammable air? This air ſtill holds in ſolution the fixed fire of the metal, which may be exhibited in its original ſtate of light when ignited in vital air, and be thence thrown back into the general maſs of light. This doctrine is further corroborated by reducing the calces of metals to the metallic ſtate in inflammable air. Put a little minium, or calx of lead, in the crucible *a*, fig. 26, Plate XVI. and place it on a ſtand under and near the top of the bell-glaſs, and place both in a baſon of quickſilver, with the ſyphon *s t*: the mouth applied at *t* may draw out the air from the bell-glaſs, and the quickſilver will riſe up to the crucible by the preſſure of the atmoſphere on that in the baſon. If then the bottle and crane, *a b*, of fig. 30, be repleniſhed with iron filings, and diluted vitriolic acid, and the crane be put under the bell-glaſs, as in fig. 30, the quickſilver will ſoon fall to the level *o o*, and the ſpace *a* will be filled nearly with inflammable air. The apparatus being expoſed to a hot ſun, and the large lens *n r* held before it, ſo that its focus may heat the minium; the air in the bell-glaſs will ſoon begin to diminiſh, and the minium to change from a red to a yellowiſh colour: as the air keeps diminiſhing, the metal revives; and if there be air enough, the calx will ſoon become ſplendid lead. What has made it ſo?—Doubtleſs its union with the inflammable air; and for the ſame reaſon that charcoal will revive a calx, or an ore, into a metal. It is true, that ſolar light, concentrated on a calx, by a large burning lens, will reſtore the calx to its metallic ſtate, and, no doubt, it aſſiſted in the laſt experiment; but this is another proof *that light is the true eſſence of all inflammability.*

From the great inflammability of this kind of air, there is reaſon to believe it is more ſaturated with latent fire than any other part of the atmoſphere; that its particles are repulſed to a greater diſtance; ſo that with as great elaſticity as common air, it poſſeſſes the ſingular property of being ten or twelve times lighter, bulk for bulk. Upon its firſt diſcovery, I thought that if a very light bag could be deviſed that would retain it, the bag and air together would be buoyed up in the atmoſphere, like a cork in water; my firſt trial was to fill ſoap bubbles with it; they ſucceeded, and were the firſt air-balloons ever made. This amuſing experiment is eaſily made by tying the mouth of a bladder to a ſtop-cock, *c*, fig. 25, Plate XVI. and ſcrewing this on another fixed on the top of a bell-receiver *a*. This receiver is filled with inflammable air, as before directed; if then the two ſtop-cocks be opened, and the receiver *a* preſſed down into the water *b*, the air will be forced up into the bladder *d*, and fill it: the ſtop-cocks being ſhut, the bladder may be unſcrewed from the receiver *a*, and a ſhort tobacco-pipe, with a little thread wrapt round its end, may be ſcrewed into the ſtop-cock of the bladder, as fig. 11, Plate XVI. When the pipe-head is immerſed in ſoap-ſuds, and the bladder a little ſqueezed, bubbles may be thrown from the pipe, that, in ſtill air, will riſe out of ſight. This effect depends entirely on hydroſtatic principles, viz. that a body heavier than its bulk of a fluid, will ſink in that fluid; for the pillar of which that body is a part, being heavier than the pillars of the fluid that ſurround it, the body muſt ſink by its ſuperior gravity. But a body that is lighter than its bulk of the fluid in which it is immerſed, will riſe up and float on the ſurface, and part of it will riſe above the ſurface. So a body being of the ſame weight in a homogeneous fluid, as its bulk of that fluid, will float promiſcuouſly at any depth in it. Air-balloons that could float two or three men in the atmoſphere, roſe on this principle. Gores of ſilk were ſewed together, ſo as to form a pear-like bag (which was made tolerably air-tight by a varniſh made of India rubber), twenty-ſeven feet in its greateſt diameter. A net of ſmall cords is ſpread over its top, terminating a little below the bottom in a ſmall baſket, in which the aëronauts were ſuſpended. A tube of the ſame materials as the balloon hung from its bottom to receive the air, and alſo to let it out when the balloon began to ſwell in the upper regions of the atmoſphere. The air was produced from zinc and iron, by diluted vitriolic acid, in leaden retorts (becauſe that acid will not diſſolve lead), and ſuſpended between two long perpendicular poles; the balloon was thus filled with inflammable air. When empty, the weight of the balloon, and two adventurers, was 604 lb.: but 20 lb. more being hung to the balloon when full, kept it in equilibrio with the atmoſphere; ſo that its power of aſcent, added to its weight, made 624 lbs. the weight of an equal bulk of atmoſpheric air, to that of the balloon, the two aëronauts, baſkets, &c. On its aſcent, the barometer ſtood at 30°, and ſoon fell to 27°, by which it was calculated that the balloon was about 600 yards above the earth; by throwing out ballaſt occaſionally as the balloon deſcended by loſs of air, it was kept about that height an hour and three quarters, on a voyage of twenty-ſeven miles.

Additional fire, added to that which the atmoſphere naturally contains, repulſes its particles to ſuch a diſtance, as to make the air, ſo heated, riſe in the atmoſphere like a cork in water: hence ſmoke is carried up by its temporary connection with heated air; and its groſs and ſooty part is precipitated back to the earth when that air becomes cooled by mixing with common air. This dictated the idea of a montgolfier, or fire-balloon, fig. 29, Plate XVI. A light paper bag, with its mouth downward, will riſe in the air, if a ſponge, *a*, ſoaked in ſpirit of wine, be ſupported a little above the mouth and ſet on fire. It is neceſſary, firſt, to inflate the bag a little by burning ſlips of paper in it; the ſponge will then burn without danger of firing the balloon; in which caſe it will often riſe above the clouds. Machines of this kind have been made of 60 feet in height, and 43 in diameter, and capable of lifting five hundred weight from the ground. Small balloons may be made by ſticking gores of ſilk-paper together with gum-water. For theſe machines to have the power of aſcending with the weight of two or three men, their volume muſt be ſo large, that their direction will always be ſubject to the wind. But, obeying the wind, they have aſcended over camps and beſieged towns, with a cord ſo attached to them that they could be drawn back to the place from whence they were launched.

Various other airs have been fabricated by art, poſſeſſing ſingular properties.

Nitrous Air, or the teſt air, is formed of the fire of any metal, united with the nitrous acid. Copper is moſt commonly uſed; being put in ſmall ſlips in a bottle, *a*, fig. 17, Plate XVI. This bottle is then nearly filled with diluted nitrous acid; and the crane-ſtopple *c* is fixed in it, and its end put under the ſhelf *d*, which has holes in it (as *z*) to let up the gas. This ſhelf is juſt covered with water; and the ciſtern in which it is fixed is deep enough to ſuffer jars and bottles to become inverted under water. The jar *e*, therefore, being filled with water in the ciſtern, and inverted on the ſhelf *d*, it receives the gas, and the water in it falls down into the ciſtern.

This criterion air unites ſuddenly with vital air, with which it forms nitrous acid, and which appears in a brown cloud; this nitrous acid is ſuddenly imbibed by water, and in proportion to the quantity of vital air contained in the mixture. Pure vital air will imbibe ſix times its bulk of nitrous air, before water will ceaſe to imbibe the two airs in the character of nitrous acid. And common air will take up a little more than half its bulk of nitrous air without its bulk being increaſed.

Theſe experiments are thus made. A ſmall glaſs cylinder, fig. 1, Plate XVII. is cemented into the braſs ſocket *c*, in which is a ſlider, *a*, that will ſhut cloſe over the mouth of the glaſs; this veſſel is called a meaſure. This meaſure being filled with water, and inverted in the pneumatic ciſtern, fig. 17, Plate XVI. and having the tunnel *m* put under it, is eaſily filled with any gas or air under water: the ſlider is then puſhed in, and the air in the mouth of the meaſure turned out, and ſo the gas or air is transferred into the long tube, fig. 5, Plate XVII. already inverted in the ciſtern and full of water. The gas ſo transferred will riſe up to the top of the tube, and expelling its bulk of water, will occupy the ſpace *x y*. If this be vital air, then may ſix meaſures of nitrous gas be added to it, and, after all, the air will only occupy the ſpace *x y*. If two meaſures of air be taken from the very cloſe and populous parts of a great city, and put into the tall tube *z x* (called an eudiometer), and one meaſure of the teſt, or nitrous air, be put to them, a brown effervescence will take place, and the three meaſures will inſtantly only occupy the place of two; diſplacing the water from *x* to *r*. The air from ſuch places may be conſidered as the ſtandard of impurity: and air from any place may be eaſily taken, and eaſily conveyed to the pneumatic ciſtern, by filling a bottle with water, and pouring the water out in the place where the air is to be taken from; the bottle then becomes filled with the air of that place, and, well corked, may be conveyed to any diſtance. By theſe two extremes, the quantity of vital air, in any common air, may be eaſily eſtimated: for as oxygen gas, or vital air, abſorbed ſix times its bulk of nitrous air, and only occupied its original ſpace, *x y*; and as two meaſures of impure air only abſorbed half their bulk of the trial air, twice ſix will be a ſcale expreſſive of the degrees of purity between *r* and *x*; i. e. if I bring a bottle of country air to the teſt, and find after two meaſures of it have abſorbed one of the criterion air, that the water in the tube will riſe above *r*, perhaps to *s*, two twelfths of the ſcale *r x*; then ſhould we pronounce *that* air to contain one ſixth more oxygen, or vital air, in it, than an equal quantity of the city air.

The firſt dozen of bubbles that come over when the nitrous air is diſtilling, ſhould be thrown away; the reſt will be very good, and will be a tolerable teſt of the proportion of vital air contained in any air. For it has been found that the duration of life, in animals confined in cloſed veſſels, keeps time nearly with this teſt; i. e. two birds, or two mice, being confined in two bell-glaſſes of the ſame ſize, one full of pure vital air, and the other of ſuch country air as above deſcribed, which would only abſorb one ſixth as much trial air as the pure air; in this caſe, if the animal in the country air lived an hour, that in the oxygen gas would live ſix hours, &c. The reaſon is plain, if we recur to what has been ſaid reſpecting breathing; for it is proved that the air taken into the lungs undergoes a decompoſition: the purer part being abſorbed by the blood in the lungs; the latent heat is let looſe and carried by the blood in an active and ſenſible ſtate through the body, thereby giving it *animal heat*; and the impure, or azotic part, is thrown out at the mouth and noſtrils. Now that air which contains *moſt* of thoſe vital principles, will ſupply life the longeſt. For the blood nouriſhing the body as it travels through the arteries, returns by the veins to the heart and lungs a thick and dark coloured fluid, and is propelled up to the lungs, to be repleniſhed with heat and vital air; it then returns into the circulation thin and florid, and capable of making its way through the fineſt ramifications of the body. Hence, to breathe air in want of its natural quantity of oxygen, is to ſend the blood unrecruited from the lungs into the circulation; thick, and incapable of being forced by the heart through the fine veſſels; theſe ſwelling, form preſſures upon the neighbouring nerves, that by degrees bring on ſpaſms, convulſions, and death. Thus died the people in the hole at Calcutta; two men in a diver's bell, in the bay of Dublin; and ſo would all land animals, obliged to breathe the ſame air over and over again. One bird, therefore, having in its air ſix times as much oxygen as the other, would neceſſarily live ſix times as long upon it. It is unneceſſary here to expatiate upon the neceſſity of breathing this pabulum as pure as poſſible; all are ſenſible of it, all feel its neceſſity; yet, with double doors and curtains, do we ſtrive to keep it from our apartments as if it were a public enemy. Many diſorders to which our forefathers were ſtrangers, date their number and malignancy from this unmanly delicacy! Why are pulmonary complaints ſo prevalent in large cities? Is it not from the ſoot, ſmoke, and putrefactive vapours we breathe? Nature has guarded the lungs, by an outwork of hair at the firſt paſs where the air enters the human frame; there its groſſer impurities are ſtopt: after it has entered the noſtrils, a crooked road to the mouth is lined with a gluey mucus, that arreſts ſmaller particles; but ſhould any of thoſe paſs theſe guards, there is a centinel at the gate of the lungs, of ſo irritable a nature, that if an atom touches him, he throws the whole frame into convulſion and reſiſtance! What has nature done all this for?—Perhaps as a hint to keep mankind from herding together, and corrupting one another in great cities. Some particles, however, will paſs this centinel in ſpite of his vigilance, and form a lodgment in the lungs; and the accumulation will be reinforced, in many, by the irritable particles of ſnuff. Matter thus accumulating in the lungs, where it cannot be digeſted, nature is obliged to throw it out by coughing, and we call the convulſion a cold! But to return.—We eſtimate the reſpirable goodneſs of atmoſpheric, or other airs, by the quantity of nitrous air which they will diſſolve: but this air has other qualities not unworthy of notice; its antiſeptic powers are greater than thoſe of fixt air; fleſh meat may be preſerved ſweet in it for ſeveral weeks, in the hotteſt weather.

Water and acid have ſo ſtrong an affinity, that four ounce meaſures of water will imbibe near 300 meaſures of nitrous air.

Nitrous acid entering into nitrous air, exhibits this acid in great variety; being an ingredient in the moſt wholeſome, the moſt noxious, the moſt pure and impure of all kinds of airs: for nitre diſtilled, yields the moſt ſalubrious vital air; but nitrous air is noxious, and cannot be breathed.

If a bottle, fig. 4, Plate XVII. be filled three quarters with common air, and one fourth with water; and a bladder, filled with nitrous air, be ſqueezed into it; the air in the bottle will abſorb the whole nitrous air, become nitrous acid, and be abſorbed by the water.

Air in which animal ſubſtances have lain ſome time in a putrid ſtate, has its putreſcence waſhed away by paſſing through water, and will bear the teſt of nitrous air. For ſmell conſiſts of the fine particles of bodies diſſolved in fire, which particles may commonly be detached from that menſtruum by mixing with water.

It is ſuppoſed that there is as much fire, bulk for bulk, in nitrous as in inflammable air.

Nitrous vapour ariſes from nitrous acid being poured on biſmuth: a brown efferveſcence iſſues with rapidity from this mixture, which, being conveyed by the bent ſtopple tube *a*, fig. 2, Plate XVII. can be conveyed into, and imbibed by, water, and other fluids. So diſtilled water, when warm, imbibes this vapour, and becomes very pure nitrous acid: and two meaſures of this water (after impregnation) become three. It alſo attacks copper more ſtrongly than diluted nitric acid.

The volatility of this vapour in water, ſo impregnated, is curious: If in an open flat veſſel a perſon blows upon it, a copious red vapour iſſues from it; and the green and blue colour of it entirely vaniſhes.

Nitrous acid diminiſhes in weight by expoſure to the air; vitriolic acid increaſes in weight. The firſt by exhaling; the latter by attracting moiſture from the air.

The end of the tube *a*, fig. 2, Plate XVII. immerſed in vitriolic acid (when the vapour iſſues from it), turns the acid blue. If water be poured upon it and ſtirred, heat, and a copious vapour, ariſes of a ſtriking appearance.

Marine acid, impregnated with nitrous vapour, is a powerful aqua regia, that will diſſolve gold without heat; and nitrous ether is made by impregnating ſpirit of wine with nitrous vapour.

Red-lead, ſtuck by moiſture to the ſide of a phial, is heated, increaſed in weight, and turned white, by the admiſſion of nitrous vapour.

The ſuperabundant quantity of fire in nitrous air immediately quits it, on being united with common air; i. e. an equality is reſtored between them.

Nitrous air diminiſhes none but reſpirable air.

The nitrous acid that enters into the copper, when diſſolving, is ſix times as much as enters into the nitrous air produced by the ſolution.

Nitrous air, imbibed by water, is expelled by heat, as well as by freezing: in the latter caſe it depoſits a ſediment.

Nitrous air is fatal to plants.

So ſtrong is the attraction of water to the nitrous acid, that it will draw it through the bladder containing nitrous air : what nitrous air remains in the bladder will become reſpirable; and the water, on which the bladder floated, will become acid.

No air can be procured from concentrated nitrous acid and metals. Water is indiſpenſable, and a conſtituent part of all airs.

Nitrous Oxyd of Azote is a gas that affects thoſe who breathe it with intoxication and madneſs! It is produced by diſſolving ſal-ammoniac in water to ſaturation; then adding nitrous acid, alſo to ſaturation; the liquor is then evaporated over a ſlow fire, till it approaches to the water of cryſtallization, when long needle-like cryſtals will appear: theſe cryſtals when dry are put in a crane-necked retort, and diſtilled over an Argand's lamp into the common pneumatic apparatus, as uſual. This ſingular gas may be breathed by a ſyphon-tube being ſtopt with the thumb, and put into the containing veſſel: two or three inſpirations will be ſufficient to excite laughter, delirium, dancing, &c. for a few moments, without the general conſequence of languor and debility.

Facts reſpecting Vital Air.—About one third of the maſs of the atmoſphere is underſtood to be vital, or ſuch air as will ſupport flame and animal life. It may be extracted by heat from nitre, from alum, from precipitate *per ſe*, from minium, from manganeſe, and from lapis calaminaris. It is found in the bladders of ſea-weed, and in freſh and ſalt water. It is produced by green vegetables, and green matter, inverted in veſſels of water, expoſed to light; for in darkneſs vegetables ſo circumſtanced give out only the fixt air they originally drew in as nutrition; but light becoming a conſtituent part of all vegetables, by the vital affinity they have to it, is elaborated with the air into the conſtitution of leaves and fruit; and when given out by them, is found to have derived from light the principle of ſupporting life and flame.

Nitrous acid produces vital air from all metallic, and other earths: heat produces it from green, blue, and white vitriols; and vitriolic acid, from minium, or red-lead.

The moſt refractory ores and metals can be fuſed by charcoal, burnt in vital air. Iron burns in it with a brilliancy too dazzling for the human eye. It enters into the calces, or oxyds, of metals fuſed in it, making them heavier than the metals themſelves; which oxyds will give out that air again in its original purity, when urged by heat, or the acids. It is only the vital part of any air that is capable of being diminiſhed by means of nitrous air.

Two ſimilar animals, incloſed in two veſſels of the ſame ſize, one filled with vital, and the other with common air, will live a length of time in proportion to the purity of thoſe airs; i. e. if in the common air there be but one third of it vital air, and the animal incloſed in that air ſhall live an hour, the animal in the vital air will live three hours, &c.

Facts relating to Inflammable Air.—This ſingular air conſiſts of fire and water, fixed by an earth. It may be expelled from metals by the heat of a large lens *in vacuo*, or when confined by quickſilver, without the intervention of water, except what is contained in all metals, and may be conſidered as the neareſt approach to elementary fixed fire of any principle in nature.

Diluted vitriolic acid expels this inflammable principle from iron and ſteel, by ſeizing the earth of the metal, and forming with it a ſalt or calx, conſiſting of the acid of the vitriol, the earth of the metal, and water for cryſtallization; while the fire of the metal and of the acid becoming active, heats the water into ſteam, thereby qualifying it to unite with the fire and part of the earth of the metal, in the character of permanent inflammable air. The new doctrine would prove this air, or hydrogen gas, to be produced by *water*. Reaſons have already been given for *metals* affording its principal ingredient. That water is a conſtituent part of it, and all other airs, I hope has been proved; as well as how water is produced by the burning inflammable with other airs.

This air is procured from regulus of antimony by marine acid; from metals, by mineral and vegetable acids; but from copper and lead, better by the marine acid. It is alſo procured by taking the electric ſpark in oil, in ſpirit of wine, and in volatile ſal ammoniac; if the ſame ſparks be taken in alkaline air, its quantity will be three or four times increaſed. Animal and vegetable ſubſtances yield inflammable air by putrefaction; and it riſes ſpontaneouſly from the mud of ſtagnant pools or ditches, where animal and vegetable matters are in a ſtate of putreſcence. It is yielded by diſtillation from vegetable earths, in quantity proportionate to its fertility: oil of turpentine, coals, wood, and all inflammable matters, yield it by diſtillation.

A few drops of ether in a blown bladder renders that air inflammable; and when common air paſſes through the flame of the oil of turpentine, it becomes inflammable; ſee fig. 6, Plate XVII.: for if the receiver *e* be exhauſted, and the flame of the oil be held to the pipe *a*, when the cock *d* is opened, the air will ruſh through the flame, and carry along with it a quantity of unconſumed oil, which will render the air in *c* inflammable.

Air pent up in the hollows and crevices of coal mines imbibes inflammation from that foſſil. This air, though ſtagnant, retains its natural elaſticity, and therefore, when the outward air becomes light, by the cauſes already mentioned, this air will ſpring from its impriſonment into the mine, more elaſtic from its acquired fire. Hence the poor miner ſhall one day take his candle with impunity to the cloſeſt receſſes of the mine, and the next, the air will take fire like a train of gunpowder, and with hideous exploſions blow up both him and the mine. The barometer ſhould therefore be conſulted before a candle is taken into a mine liable to ſuch baleful damps, as they are called.

Inflammable air, mixed with fixed air, burns with a blue flame; with nitrous air it burns with a green flame; but when mixed with an equal quantity of vital air in an air-piſtol, its exploſive power will diſcharge a bullet almoſt as forcibly as gunpowder. It is imbibed by water when agitated in it, and may be expelled from it by heat in the ſame ſtate.

Inflammable air is fatal to animals; and inſects become benumbed and paralytic in it. It reſtores the calces of metals to their metallic ſtate; for if minium be expoſed in it under a glaſs receiver, and the focus of a burning-glaſs be made to heat the calx, it will begin to imbibe the air, turn yellow, and in time will drink up the whole, and become real lead.

This air refracts the rays of light more than common air, and is eight or ten times lighter.

On Fixed Air.—This wonderful antiſeptic has been called aërial acid, fixable air, and now the carbonic acid, as ſuppoſed to be derived from charcoal and oxygen. Diſtilled charcoal certainly produces a gas that has ſome qualities in common with that expelled from chalk, and other calcareous matters, as well as that produced by vegetable fermentation: but though theſe have been all called by the general name of fixed air, they each poſſeſs peculiar qualities, very different from each other.

Fixed air is heavier than common air; is a weak acid; but capable of holding various ſalts together, by its affinity to their alkaline baſes. It is a conſtituent part of chalk, marble, limeſtone, ſhells, &c. but eaſily expelled from them by heat, or ſtronger acids. Hence the vitriolic acid drives out the fixed air from theſe ſubſtances; ſo does the fire of the lime-kiln; and leaves the earthy baſes cauſtic, greedy, and rapacious, to tear fixed air from any thing that contains it; diſſolving animal and vegetable ſubſtances, and rendering acrid ſalts mild (for ſalts that are duly ſaturated with fixed air are ſaid to be mild; and thoſe that have an affinity to fixed air without being poſſeſſed of it, are ſaid to be cauſtic). It is contained in ſalt of wormwood, in Glauber's ſalts, in alum, in vitriolated tartar, from all which it can be expelled by the acids. Nitrous acid expels it from wood and coal-aſhes; ſo that a vegetable phœnix may be ſaid to ariſe from thoſe aſhes: for as the nidus of nitre is ſpread over the earth, and its acid may be made volatile by the heat of the ſun, may not this acid attach itſelf to this reſiduum of fire, and form with it a fixed air, that (from its ſuperior weight) will fall down to the roots of plants, and become their principal nutrition? and thence have a reſurrection from a *caput mortuum* to vegetable and animal life? As an acid, one meaſure of fixed air will ſaturate three meaſures of alkaline air, and will turn red-roſe leaves white. It is fatal to vegetables in air and water, but ſalubrious in earth; not ſoon fatal to inſects. Water impregnated with fixed air kills fiſhes.

Water has a ſtrong affinity to this air; it imbibes it almoſt in its paſſage through it; and thence acquires the acidulous taſte, the ſparkling appearance, and medical qualities, of the Pyrmont and Spa waters; and when made in the following manner, as exhibited in fig. 3, Plate XVII. may be made much ſtronger, and in large quantities. *a* is a barrel ſuſpended on the pillars *c* and *d*: in the head of the barrel, *n*, there is a ſocket of braſs or iron, into which the fixed and hollow axle *o* exactly fits; ſo the barrel turns upon it. The bottle *x* contains the chalk, and diluted vitriol, which may be inſerted or repleniſhed through the ſtopple *p*: *z* is cylindrical bellows, made of varniſhed leather, very cloſe, and on which the weight *s* may be occaſionally laid. When the cock *o* is ſhut, and the efferveſcence is going on in the bottle *x*, the bellows will fill. If the barrel *a* be nearly filled with water, the cock *o* be opened, the barrel ſwiftly turned by the handle *g*, and the weights laid on *z*, to force the fixed air into the barrel, the water in it will become ſtrongly impregnated. By this means any quantity of water may be medicated with ſmall labour and expence; and when quickly bottled, and well corked, will continue good many months.

There are many methods of impregnating water with fixed air; but without ſtrong agitation the water never becomes ſufficiently ſaturated.

The antiſeptic properties of this air and medicated water are numerous and remarkable. The ſaline draught is ſalubrious, by diſcharging fixed air in the ſtomach. Sugar, malt, preſerved vegetables, &c. boiled, and in a ſtate of fermentation, given to patients in the ſea ſcurvy, have reſtored and preſerved men in health even in a voyage round the world. The medicated water, mixed with tartar, has, in many inſtances, diſſolved the ſtone in the bladder. Inflammation in the bowels has been cured by a clyſter of fixed air. Chilblains, and legs in the firſt ſtages of a mortification, have been cured by being incloſed in bladders ſupplied from bottles containing chalk and diluted vitriolic acid. Fixed air, mixed with inflammable air (hydro carbonate), has been breathed with common air in conſumptive caſes with great advantage, and has operated as a ſtyptic in the lungs in caſes of a ruptured blood veſſel; though fixed air alone irritates the lungs, and cannot be breathed. Inflamed nipples have been cured by forcing the air upon the part. So powerfully does it reſiſt putrefaction, that a piece of mutton, hermetically ſealed up in fixed air, has preſerved its texture and appearance above twenty years. Fixed air extinguiſhes a candle; and even a train of gunpowder, leading into the grotto del Cano near Naples, was extinguiſhed on entering the part where the heavy fixed air lies. A candle will not burn under the clothes when a perſon has been for ſome time warm in bed, nor in common air that has been breathed. To blow through a bent tube of glaſs, containing a little lime-water, will revive the limeſtone; the water turns turbid, and the ſtone is precipitated. Lime-water is therefore a teſt of fixed air being a part in any air to which the water is expoſed. As both breathing and heat, therefore, expel a quantity of fixt air from the human body, it is reſtored by a due mixture of animal and vegetable food, which, going into a ſtate of fermentation in the ſtomach, generates a quantity there; and the moiſture of the ſtomach imbibes, and carries it into circulation. Hence the ſea ſcurvy derives it greateſt malignance from the want of vegetables.

This gas is diſcharged in large quantities by fermenting liquors; it is generated in coal-mines, and called the choak damp. It is alſo found in wells that have been long ſhut up, in both which it has proved fatal to perſons immerſed in them. It is equally dangerous in rooms where charcoal is burnt without a chimney.

On Marine Acid Air.—This air is procured by diſtillation from marine acid; and from common ſalt and vitriolic acid, through quickſilver. The pond of mercury, through which ſuch experiments are made, is generally in a piece of ſolid wood, hollowed as fig. 7, Plate XVII. The cavity *a*, in the top of the pond, is the ſame as *c*, ſeen in a profile. This hollow is filled with quickſilver, and ſpreads thinly over the ſpace *d d*; ſo that ſuch receivers as *w* may be filled in the hollow part *c*, and placed inverted on the ſpace *d d*. The bottle *s* being three fourths filled with table ſalt, and a hole, *n*, made in the ſalt with a pointed ſtick; if this hole be filled with vitriolic acid, a briſk effervescence will enſue, and marine acid air will riſe through its crane ſtopple *x*, and expel the quickſilver in *w*. A lighted candle held under the bottle *s*, will accelerate the diſcharge of air. An equal quantity of alkaline air being put to this, both inſtantly diſappear as air; and ſal-ammoniac is produced. Water abſorbs this air, and the union produces marine acid. This air extinguiſhes a candle with a blue flame. It diſſolves iron, ſulphur, and nitre. It diſſolves ice; makes camphor fluid, and blue vitriol green. In ſhort, it is but the marine acid in a ſtate of permanent vapour.

On Alkaline Air.—This air is generally expelled by a candle from the bottle *s*, fig. 7, Plate XVII. filled one fourth with pounded ſal-ammoniac, and three fourths with quick lime mixed: it is, in reality, but volatile alkali in the form of air; mild when mixed with fixt air, but common ſal-ammoniac when united with marine acid air.

We have noticed that the electric ſpark taken in alkaline air, turns it into inflammable air, and increaſes its quantity three times.

As an alkali, it is abſorbed by acid airs in this proportion.
By fluor acid air, twice its quantity.
By vitriolic acid air, ditto.
By marine air, and by fixt air, about an equal quantity.

On Fluor Acid Air.—This air is procured by diſſolving pounded fluor (Derbyſhire ſpar) in hot vitriolic acid; or by juſt covering the ſpar with the acid in the bottle *s*, fig. 7, Plate XVII. and expelling the air, by a candle, through quickſilver into the receiver *w*. This air has the property of diſſolving glaſs, and will etch it like a copper-plate, if the plate, or jar, be firſt covered with a thin coat of molten bees-wax on both ſides, and when cold, engraven with the point of a needle on one ſide; ſo prepared it ſhould be put in the box *a*, fig. 8, Plate XVII. This box is about eighteen inches by ſixteen, lined with ſheet-lead, having a lid *n*, and a double bottom *x*, to diſtribute the gas equally among the pieces to be etched, which are placed properly for that purpoſe within the box. About a wine-glaſsful of bruiſed ſpar is then put in the ſtone retort *s*, and as much vitriolic acid as will cover the ſpar. The leaden pipe *r* is then luted upon the neck of the retort, and into the falſe bottom of the box *a*, of ſuch a length that the wax on the glaſs, within the box, may be in no danger of melting by the fire *z*. This fire may be very gentle, for a ſmall heat will expel the gas; and the more equally and ſlowly it flows among the pieces to be etched, the more perfect will be the effect. Cyphers, arms, foliage, landſcapes, or writing, will be completely etched by the gas in two or three hours, or furniture, window, or other glaſs.

The jar *w*, fig. 7, Plate XVII. being filled with fluor acid air, and removed out of the quickſilver into water (by placing a ſmall veſſel under its bottom), the water will ſeize the acid, and abſorb the air; while the earth of the ſpar, and the ſiliceous matter diſſolved from the glaſs, will be precipitated in flakes through the water.

From theſe details, it is eaſy to conceive how very various the atmoſphere muſt be over the different ſoils and climates of the earth; and how far this variety is capable of being imitated, improved, or contaminated, by the means of art. Thoſe airs capable of being produced by ordinary heat, no doubt are mixed and diffuſed through the general maſs of the atmoſphere; and where that heat is greater, and the exterior products of nature more volatile, as in the torrid zone, the variety and changes muſt be very great and different to thoſe of the more temperate climates: yet in all, the atmoſphere may be conceived as made up of *the finer particles of terreſtrial matter diſſolved in ſolar fire*: and art has inſtructed us what parts of matter are the moſt ſuſceptible of becoming atmoſpheric; viz. water; calces of metals; metals themſelves in certain circumſtances; volcanos; calcareous earths; acids; alkalis; ſalts; flowers, and leaves of vegetables; artificial fires; many effects of arts and manufactories; animal and vegetable fermentation, putrefaction, &c.

SECTION II.

On Winds.

A WIND is air in motion; its cauſe is partial heats and partial colds on the earth and in the atmoſphere; for heat rarefying the air, makes it occupy a greater ſpace, and therefore to be bulk for bulk lighter than colder air; and a heavier part of the fluid will always tend towards, mix with, or diſplace a lighter. Hence a large fire in a room will always cauſe a buzzing at the key-holes and crevices of the room; for the air over the fire being heated, the pillar of air, of which the chimney is a part, will be lighter than the pillars at a diſtance, and therefore the heavy air will ruſh through thoſe obſtructions, and produce a wind in miniature: thus fire becomes an uſeful ventilator, and treats the room with perpetual freſh air.

In going out of a great city in winter, a wind is always *met* in every point of the compaſs; for the heat of ſo many fires, people, and animals, making the air ſo much hotter than in the neighbourhood, the country air ruſhes in at the exterior ſtreets, bringing its ſalubrious qualities along with it, and buoying up the light and contaminated air into the upper regions of the atmoſphere, to mix with the general maſs.

The more extenſive winds owe their origin to the ſun; for ſandy, loomy earths receive from the ſun, and deliver to the air, more heat than water, ſwampy bogs, woods, or cultivated lands do. Clouds and fogs often obſtruct the rays of the ſun, and abſorbing their heat, reduce them to a latent ſtate. Many ſubſtances on the earth's ſurface having a ſtrong affinity to light, imbibe and render it latent. Theſe cauſes keep the air in a ſtate of perpetual fluctuation. Beſides, as tranſparent mediums, ſuch as clear air, clear water, clear glaſs, &c. ſuffer light to paſs through them, they receive little or no heat from ſolar light; inſomuch that the opaque earth, receiving its heat from the ſun, imparts it to the contiguous air: and hence the air is warmeſt near the earth, and grows colder and colder the higher we aſcend in it.

The *day* breeze from the ſea towards and over the land, and the *night* breeze from the land to the ſea, in the torrid zone, are accounted for from theſe principles. The land heats the air, and the cold ſea breeze, pouring on the land, buoys up the heated air into the upper part of the atmoſphere. Let *a*, fig. 9, Plate XVII. repreſent an iſland in the torrid zone, with the winds blowing upon it from the ſea, in the direction of the ſurrounding darts: thoſe winds meeting in the centre of the iſland at *a*, in oppoſite directions, will neceſſarily ſo accumulate at *a*, as to riſe above the common level of the neighbouring part of the atmoſphere. This will continue while the ſun is up; but on his ſetting, the cauſe ceaſing, this protuberance will naturally deſcend to the level, and preſſing out from the land, will cauſe the night breeze, which always ſets from the land upon the ſea.

That part of the coaſt of Africa within the torrid zone has (like many others ſo ſituated) its day and night breeze, which reaches a conſiderable way from the ſhore (ſee fig. 10, Plate XVII.); but the ſea breeze being from the weſt, as *a*, *a*, *a*, while the trade winds blow from the eaſt, as *c*, *c*, *c*, a chaſm takes place between them, *x*, *x*, *x*, where the air becomes ſo rarefied, and, of courſe, ſo diſpoſed to let go the water diſſolved in it, that this intermedium becomes liable to perpetual calms, rain, and lightning. Irregularities in this intermedium cauſe the harmatan, a foggy, hot, deſtructive wind, blowing from the interior part of Africa towards the ſea, three or four times in a ſeaſon, and continuing ſometimes ſeveral days. For when hurricanes take place in the Weſt Indies, or extraordinary rarefactions or heats in South America, the trade wind will increaſe, to reſtore an equilibrium, and draw the intermedium, *x*, *x*, *x*, more out at ſea, or to the weſtward: this will render the ſea breeze, *a*, *a*, *a*, tame and weak upon the African ſhore, and the interior air will flow towards that ſhore, to preſerve a level.

The *trade winds* blow from the eaſt towards the weſt, for thirty degrees on each ſide of the equator, acroſs the Atlantic and Pacific Oceans; inclining a little towards the N. W. when the ſun is near the tropic of Cancer, and towards the S. W. when the ſun is on, or near, the tropic of Capricorn. Thus following the ſun, it is evident the ſun is the cauſe; for though perfectly tranſparent mediums do not receive heat from ſolar light, the ſea is ſeldom in that ſtate, or even the air; and, therefore, both will be warmed by the ſun in his paſſage from eaſt to weſt; not only on the parallel over which he paſſes, but a conſiderable diſtance to the north and ſouth of it; ſo that the colder air following the warmer, will make a continual current from eaſt towards the weſt, over the torrid parts of the Atlantic and Pacific Ocean.

Another hypotheſis reſpecting the trade wind is, that, as the air is very thin, or in a greatly rarefied ſtate, by the heat of the ſun, in the torrid zone, the earth, turning on its axis from weſt to eaſt, will leave this light air behind; ſo that, in reſpect to the earth's ſurface, this air muſt ſeem to move the contrary way, or from eaſt to weſt. But certainly, in the courſe of a ſhort time after the earth began its diurnal motion (as the air is held faſt to the earth by the power of its attraction), this air would acquire the ſame motion as the earth, and then they muſt move together.

The *ſirocco* is a ſouth wind blowing over the ſandy deſerts of Barbary and Tripoli, and over the Mediterranean. Thoſe ſands receive ſuch a degree of heat from the ſun, and impart ſo much of it to the air, as to qualify that air to take up more water in ſolution than almoſt any other; hence the ſurface of the Mediterranean is lowered, and occaſions a perpetual current, or influx, at the Straits of Gibraltar; and the hot air becomes ſo loaded with vapour, by the time it arrives in Italy and Greece, as to be ſuffocating, oppreſſive, and almoſt intolerable to the inhabitants of thoſe countries. Winds blowing from the ſea are always moiſt, bringing, like the ſirocco, copious exhalations with them: but winds from a continent are always dry; warm in ſummer, and cold in winter.

The cauſe of a N. E. wind, as well as its exceſſive cold, is a north wind ſetting ſouth over evaporating ice, to reſtore equality with the warmer ſouth: but being turned out of its ſouth direction by the *ſwifter* motion of thoſe regions of the earth it paſſes over eaſtward, it acquires obliquity, and flows from the N. E.—S. W. winds are warm, becauſe they are ſouth winds turned out of their northern direction by the rotation of the earth on its axis (as before); and directed towards the N. E. becauſe they arrive at a part of the earth's ſurface which moves *ſlower* than the ſurface nearer the equator from whence they came, and of which they had previouſly acquired the velocity.

Air near the freezing point loaded with moiſture, gives greater ſenſation of cold than any other air, by the evaporation of little aſſemblages of water on the ſkin.

We often ſee one tier of clouds moving one way, and another tier moving under them in a contrary direction. A ſudden rarefaction in any place will cauſe the neighbouring cold and heavy air to ruſh into that place with ſuch rapidity, as to diſplace, or drive up, the hot air without cooling it: but that rapidity will occaſion a rarity behind it, to which the light diſplaced air will have a natural tendency, to reſtore an equilibrium, and two currents of air will be then ſeen moving in contrary directions. This effect may be ſeen in an hot room, by opening a door into a cold one; for if a candle be held near the top of the door, the flame will be forced out of the hot room into the cold one; but if placed at the bottom of the door, the flame will be forced into the hot room. Heated air always forms a ſtratum at the ceiling of a room; which, by its greater elaſticity, preſſes out at the top of the door; while the heavy cold air preſſes in at the bottom to reſtore the balance. Hence the ſuperior wholeſomeneſs of breathing in high, rather than low, rooms: for when we inſpire or *draw in* the air, it flows radiantly from the general maſs to the mouth and noſtrils in the direction of the darts, as *a*, fig. 11, Plate XVII.: but when we expire, or eject the air *from* the mouth and noſtrils, the heat it has acquired in the lungs makes it lighter than the air into which it is ejected, ſo that it is buoyed up into the upper part of the room, out of the way of being breathed again, as the darts iſſue from *d*.

The *monſoons* are periodical winds affecting the ocean to the ſouthward of Arabia, Perſia, India, &c. which countries are ſubject to exceſſive heats, when the ſun is north of the line, and nearly vertical to them; the winds, therefore, ſet from the ſouth-weſt along the eaſt coaſt of Africa, and up the Bay of Bengal, from the month of April to the latter end of September, obeying that influence. But from October to April, when the ſun paſſes over the meridians of the above places, and ſhines only on a vaſt ſea, without land to receive his heat, and impart it to the air, that air will be heavier and colder than the air over Borneo, Java, New Holland, and the Molucca Iſlands; and, therefore, will flow towards thoſe iſlands, making a monſoon from the north-weſt towards the ſouth-eaſt, ſouth of Cape Comorin; and from the north-eaſt to the ſouth-weſt in the Bay of Bengal, and along the eaſt coaſt of Arabia and Africa; becauſe the heated parts of Africa, over which the ſun paſſes, and the cold occaſioned by the ſnows on the mountains to the north of India, form ſuch a diſparity, that the colder and heavier air ruſhes towards the warmer and lighter, according to the bearings of thoſe countries, viz. from the north-eaſt to the ſouth-weſt.

The force of wind is nearly as the ſquare of the velocity, i. e. if on a ſquare board, expoſed to a wind, there be a preſſure of one pound, if another wind has double the velocity, it will preſs the board with a force equal to four pounds, &c. Or if a body moving through ſtill air be reſiſted with a force equal to one pound, if that body move twice as faſt, it will be four times as much reſiſted, &c. Wind, therefore, that travels

1.47	feet in one ſecond of time, is hardly perceptible.
2.93	juſt perceptible.
4.4	
5.87	gentle pleaſant wind.
7.33	
14.67	pleaſant briſk gale.
22.	
29.34	very briſk.
36 67	
44.	high wind.
51.34	
58.68	very high.
66.	
73.35	a ſtorm, or tempeſt.
88.	a great ſtorm.
117.36	an hurricane.

Bodies falling through the air are accelerated in their deſcent, till the reſiſtance of the air becomes equal to the momentum, or moving force of the body, and then its motion will increaſe no longer, but it will move on with an equal velocity. For ſo much does the reſiſtance of the air retard the motion of bodies, moving through it with conſiderable velocity, that cannon balls, which can only be projected two or three miles, by the power of gunpowder, would fly twenty or thirty in vacuo. By the motion of a cannon ball, the air becomes greatly compreſſed before it, and rarefied behind it, inſomuch, that a miſt may be ſeen preceding the ball.

Winds paſſing over the ſurface of water plough up the latter into waves; for air and water have ſuch an affinity to one another, that they unite both chemically and mechanically with each other; water being abſorbed into the air, and air into water; both which, as before obſerved, may be detected by the air-pump. When a maſs of air, therefore, preſſes on the ſurface of a body of water, they combine, link as it were together; and hence air never paſſes ſwiftly over water, but it harrows up its ſurface into waves. Inſomuch that a pretty ſtrong wind blowing up a ſtraight canal of four miles in length, will raiſe the water four inches higher at the lee end, than at the windward end of the canal. But if any intermediate matter could be interpoſed between the air and water, that would interrupt that affinity, or ſuffer the air to ſlide over water without mechanical friction, or chemical attraction, waves might be prevented, or ſtilled when raiſed. Oil, and ſaponaceous matter, has that affect; for if, on the windward ſide of a pond, a cruet of oil be poured when the pond is in a ſtate of high agitation by wind, the repulſion between oil and water (or the abundant fire contained in the firſt more than the latter) will ſpread the oil like a fine ſkin over the whole pond in a few ſeconds. This ſtratum ſuffers the air to ſlide over the ſurface of the water with ſuch ſmoothneſs, that the wind ſerves to beat down the waves inſtead of raiſing them. Hence ſhips have been ſaved by ſtaving a caſk of oil on entering a ſhallow harbour in a ſtorm. The ſtrong repellency of oil and water is beautifully exemplified in the manufactory of marble, paper, and other wares, where colours and oil, mixed very thin, are ſpread by a pallet-knife on water, and ſtirred; paper, duly prepared, will aborb the oil and colour in the ſame ſtriated form in which it lay on the water. When oil is dropt on water, it inſtantly ſpreads in circular priſmatic colours; its motion agitates ſmall bits of paper; and a conical piece of paper ſoaked in oil, when placed on clean water, moves whimſically round. As obſerved before, a ſubtil effluvium iſſues from all bodies ſuperabundantly poſſeſſed of fire, as is the caſe with inflammable oils, which effluvium receives ſuch reaction from the water as puts light bodies in motion.

If a tumbler glaſs be ſuſpended by a ſtring, and half filled with water, and is made to ſwing like a pendulum, the water will remain ſtill, keeping its ſurface always perpendicular to the ſtring. The ſame effect takes place when the tumbler is half filled with oil. But when oil is poured on the water, and continues ſwinging, the ſurface of the oil will remain level, and perpendicular to the ſtring, while the water below, will undulate ſo as to keep its ſurface always tending towards a level with the horizon, and ſwell like the waves of the ſea. This ſtriking experiment has been variouſly explained; it has generally been thought to ariſe from the different ſpecific gravities of the two fluids: but when quickſilver and water are made to ſwing to and fro, no ſuch undulation takes place! the ſurfaces of both keep parallel, and both perpendicular to the ſtring. This may perhaps ariſe from the too great difference of ſpecific gravity between quickſilver and water; and the above effect may only take place between fluids that are not very different in their ſpecific gravity.

The *air-gun* derives its power from the elaſtic force of compreſſed air. A ball, *a*, of caſt-ſteel, fig. 12, Plate XVII. having a conical valve that opens inward, and which is kept cloſe ſhut by the ſpiral wire-ſpring *c*, air tight, is ſcrewed at *n* upon the forcing ſyringe *s*: this ſyringe has a ſolid piſton *r*, which can be drawn below the hole *z*, by placing the feet on the croſs-bar *m*, and pulling by the two handles *y y*: the air will then fill the ſyringe through the hole *z*. If then the piſton be forced to the top of the ſyringe, it will drive the air up before it into the ball *a*, which the valve *c* will keep there. Theſe ſtrokes repeated twenty or thirty times, will make the air within the ball ten or twelve times as denſe as the common air, and to have the force of gunpowder. The ball now taken from the ſyringe, and ſcrewed under the gun, fig. 13, Plate XVII. will diſcharge twenty balls ſucceſſively; for a pin *o* goes through the barrel of the gun, and terminates on the conical valve above mentioned; and the lock of the gun being cocked by the hook *s*, is diſcharged upon the pin *o*, by pulling at the trigger: the pin puſhes open the conical valve, and lets out a ſmall portion of air, but enough to force a ball through an inch board at thirty yards diſtance. This may be repeated twenty times with the ſame charge, and almoſt with the ſame force.

The *magazine wind-gun* is ſtill a more formidable inſtrument. It contains a magazine of balls, ſhut up in the ſerpentine tube *a*, fig. 1, Plate XVIII. This tube has a continuation through the cylinder *c c*; which cylinder goes through and acroſs the barrel of the gun, the end of which can only be ſeen in the drawing. This cylinder is of ſolid braſs, and can be turned by the hammer *m*, ſo as to coincide with the magazine; and if the gun be held perpendicularly, the ball *s* will fall into the cavity *o*, where it will be ſtopt by two ſmall and ſlender ſprings ſeen at *o*. If now the pan be opened, the hammer will be in the ſame poſition as in the drawing, and the ball *z* will be in the barrel of the gun, ready to be diſcharged. This gun has its charging ſyringe in its butt; *k* is its piſton; this being drawn below the hole *u*, the ſyringe will become filled with air, which, by puſhing the gun downwards, will be forced through the valve *b* into the outward barrel of the gun, A A; which is to hold the condenſed air: twenty or thirty ſtrokes will charge the gun, and qualify it to diſcharge the magazine of balls one after another, as faſt as the gun can be cocked, and the pan opened. The communication between the inner and the outer barrel is made by the valve *x*, which is conical, and preſſed down by the long ſpring *g*, ſo as to keep the gun ready charged for ſeveral months. The cock of the gun is united with the piece *e*; which, when pulled back, or cocked, preſſes down the ſtrong ſpring *q*, and the catch *r* keeps it in that poſition, till the trigger *t* diſengages it; the lever *v* being, by this means, ſuddenly ſtruck againſt the pin that is faſtened to the valve *x*, opens it temporarily, and a portion of the condenſed air ruſhes out behind the ball *z*, and diſcharges it with the force of gunpowder. By theſe devices may twelve balls be diſcharged in ſucceſſion in as many ſeconds. It is obſervable, however, that if one of thoſe guns be kept charged for ſeveral months, the air will loſe much of its force and elaſticity. The latent fire of the air is ſqueezed out by its compreſſion, as may be felt by the ball of the air-gun growing warm while it is charging, ſo that the air within having loſt much of that which gave it elaſticity, coaleſces into an inert fluid in time.

SECTION III.

On Sound.

ALL elaſtic ſolids, or fluids, are conductors of ſound. The air is one of the moſt elaſtic fluids in nature; and, therefore, pervading all places in and upon the earth, it is the moſt proper medium for conveying auricular intelligence from one creature to another. As fire is a conſtituent principle in moſt parts of ſolid and fluid nature, particularly in thoſe parts ſuſceptible of ſound and vibration; and as thoſe bodies that ſhew the leaſt ſigns of poſſeſſing fire, ſuffer ſounds to paſs through them with the moſt difficulty, as marble, chalk, and other incombuſtible ſubſtances, it is natural to conclude, that fire is the univerſal cauſe of the elaſticity in all vibrating, or ſonorous bodies. If my hand moves ſwiftly through the air, the air will be driven into a condenſed ſtate before my hand, and into a rarefied ſtate behind it; but it will make no ſound, and ſoon reſtore itſelf to an equality: the motion of a muſical ſtring does the ſame; it condenſes the air before the ſtroke, and rarefies it behind; but ſo ſwiftly do the impulſes ſucceed one another, that the air is forced into ſucceſſive waves that emanate from the ſtring globularly, and travel at the rate of 1142 feet in one ſecond of time. This is eaſily eſtimated by ſeeing and hearing a gun fired in the night, at 1142 feet diſtance, when the light would be ſeen one ſecond ſooner than the report would be heard. Theſe waves from a ſtring, or bell, may be better underſtood from fig. 2, Plate XVIII. where the ſtring vibrates from *a*, &c. When any obſtruction meets theſe waves, they rebound back and produce echo; ſometimes perpendicularly, and ſometimes obliquely: when the waves ſtrike inclined upon a reflecting ſurface, then may the echo be heard, and not the original ſound, as fig. 3, Plate XVIII. where the direction of the wave *a c* being againſt the oblique wall *d*, the ſound will be reflected to an ear ſituated at *m*; and if a hill ſhould lie between the bell at *a*, and the ear at *m*, then will the echo be heard at *m*, and not the original ſound of the bell. If the head *r* ſtands oppoſite to the rock *s*, and repeats 1, 2, 3, 4, 5, 6; and the word *ſix* gets out of its mouth before the word *one* returns to its ear, as in the fig. 4,

Plate XVIII. it will hear the whole ſix ſyllables diſtinctly repeated. But if it be too near the rock, the word one will return before the word ſix leaves the mouth, and then the echo will be confuſed: if the diſtance is ſufficiently increaſed, not only ſix, but even twelve, ſyllables, will be repeated by the echo.

The remarkable echo in the dome of St. Paul's church, depends on the ſame principles. If an ear be placed diametrically oppoſite to a mouth (in what is called the Whiſpering Gallery), though many yards diſtant, the ſmalleſt whiſper will be diſtinctly heard. Fig. 5, Plate XVIII. The natural or rectilinear ſound will paſs acroſs the dome from *a* to *b*. The waves that paſs from *a* to *d*, impinging upon *d*, will, according to the angle of incidence and reflection (ſee Optics), be reflected to the ear at *b*: and the waves that ſtrike the dome at *c* will be reflected to *d*, and from *d* to *e*, and from *e* to the ear at *b*. So it will be with all the aliquot, or even, diviſions of the ſemi-circle *a*, *c*, *d*, *e*, *b*; as well as the other half, *a*, *g*, *b*; ſo that it may be ſaid that not an atom of any wave that ſtrikes the wall is loſt, but that they all aſſemble at the ear *b*; conſequently the ſenſation is as if the mouth and ear were cloſe together. But if the ear and mouth are not diametrically oppoſite, the words will be heard double; for one arch being leſs than the other, the ſound will arrive at the ear ſooner round the ſhorter arch than the longer.

Water is an excellent conductor of ſound, and greatly aſſiſts echo. The remarkable echo of Simonetta, near Milan, is over arcades of water. Another, near Rouen, is over ſubterraneous caverns of water. In calm weather a whiſper may be heard acroſs the Thames.

Sound is capable of being condenſed in a tube, or ſpeaking trumpet, ſo as to penetrate through the air to a great diſtance, in one line. For all the waves that fly off globularly from a ſounding body, are by this trumpet condenſed into one line, and, therefore, its force becomes great in proportion. The mouth of this trumpet opens (or ſhould open) in the logarithmic curve: this curve has the property of reflecting the waves, that ſtruggle to diſperſe at the mouth of the trumpet, into the axis of the inſtrument, as repreſented by the ſpotted lines, fig. 6, Plate XVIII. agreeably to the law of the angle of incidence and reflection in Optics. This is the trumpet's effect both in receiving and delivering ſound; for waves ſtriking the mouth of the trumpet, B, from without, become condenſed in the tube, and ſtrike an ear at *c* with the compreſſed force of all the waves that cover the mouth of the trumpet: hence its effect in aſſiſting deafneſs. If two trumpets, as A and B, be placed in the axis of each other (as in the figure) at forty or fifty feet diſtance, the ſmalleſt whiſper at *a* would be heard diſtinctly by an ear placed at *c*; and *vice verſâ:* ſo that a perſon might aſk a queſtion at *a*, and receive an anſwer from *c*. The anſwers ſeemingly given by the ſuſpended *Speaking Figure*, is a trick founded on this principle.

Two bodies of air, ſtriking againſt each other, produce thunder; for lightning either burſting in, or darting through the air, will ſeparate it, and cauſe a vacuum; ſo that the ſeparated bodies of air coming together, and ſtriking progreſſively againſt each other, cauſe the long-reiterated report of thunder: reverberation from clouds, mountains, &c. alſo contribute to this effect. So it is in the report of a gun: flame, by its repulſion, univerſally diſplaces the air; the rarefaction of both air and the moiſture produced in firing gunpowder, contributes to extend the vacuum; hence the quick return of the air into the gun makes it ſtrike the bottom of its barrel with a force capable of producing a loud report; for it muſt be remembered, that in proving the particles of air to be hard, a column of air was ſuffered (in the firſt Lecture) to fall on the plate of an air-pump, which produced as loud a report as that of a common gun. Hence alſo the reaſon why an air-gun can ſcarce be heard; for the diſplaced air, returning, falls on a cuſhion of rarefied air within the barrel.

If a rope be ſtretched tight between two points, thirty or forty feet diſtant from each other, as *a* and *b*, fig. 7, Plate XVIII. and ſtruck with a ſtick, the whole rope will not vibrate, but ſeveral ſtill places will be ſeen in it, between which the parts of the rope will vibrate, as from *a* to *c*, and from *c* to *d*, &c. The diſtance of theſe ſtationary places is always an even or an aliquot part of the whole rope; as from *a* to *c* is half its length; from *b* to *d*, one fourth its length, &c.

Hence ariſe the wild and wonderful harmony of the Eolian harp; for though the inſtrument may have twenty ſtrings, all tuned uniſon to one another, yet do we hear not only the natural ſound of each ſtring, but its octave, fifth, third, twelfth, fifteenth, &c. A current of air is certainly a delicate fiddlebow; it affords a ſtring (by the equable impulſe upon its whole length) an opportunity of dividing itſelf into a number of imaginary bridges, to which it has a natural tendency. Hence every ſtring becomes capable of three, four, and more ſounds; thus *a*, *b*, fig. 8, Plate XVIII. are the uſual bridges of the ſtring *a*, *c*, *b*, from whence the ſtring has its natural key: the moſt important imaginary bridge is at *d*, which is in the middle of the ſtring: half the ſtring having but half the *vis inertiæ* of the whole ſtring, will, therefore, vibrate twice as faſt as the whole ſtring; every ſecond wave, therefore, coming in contact with the waves of the original ſtring *a b*, gives a pleaſing ſenſation to the ears, and the union is called an octave. Another bridge takes place at *e*; the vibration of *a e* is thrice, while the whole ſtring is twice; hence every third wave of *a e* coincides with every ſecond wave of *a b*, and produces the concord called a fifth. The remaining part of the ſtring *e b*, being half the length of *a e*, is, of courſe, an octave to *a e*, and a twelfth to the whole ſtring *a b*. The part of the ſtring *c b*, is ſeven ninths of the whole ſtring, and gives the major third to it, &c. Thus are the leading notes of the octave capable of being performed by one ſtring, or one bell; ſuch is the tendency that motion has to divide itſelf into proportional parts. The artful performer on the violin avails himſelf of this tendency, by gently touching the aliquot parts of a ſtring; by which he aſſiſts nature in forming the bridges, and produces thoſe pipe-like tones called harmonics.

The pulſations, or waves, cauſed by the quick vibrations of a ſtring, or bell, may be further illuſtrated by the mechanical ſympathy among accordant ſounds, viz. If two ſtrings, on two inſtruments, are tuned uniſon, and one be ſtruck, at ſeveral yards diſtance from the other, that other will reply; for the waves made by the firſt ſtring being the ſame that would be made by the ſecond if ſtruck, thoſe waves give a mechanical ſtroke to the ſecond, and produce its ſound.

2d. So in the Eolian harp, if only two of its ſtrings are uniſon, and a piece of paper be hung on one of them, all the other ſtrings may be ſtruck without effect; but when the uniſon ſtring is ſtruck, the paper is inſtantly ſhaken off.

3. In like manner, when the dampers are taken from the ſtrings of a piano-forte, the inſtrument will repeat the key of every word ſpoken in the room.

4th. A wet finger preſſed round the top of a wine-glaſs, will produce its key; or if it be ſtruck with a ſmall key, its *pitch* will be produced. An uniſon, or octave, to that pitch being ſtrongly excited on a violoncello, the glaſs will begin to dance, and, perhaps, be ſhaken off the table.

5th. Thoſe unacquainted with this mechanical ſympathy, are much aſtoniſhed to ſee a looſe pannel in a wainſcot begin to dance in its mortice, when a particular note is produced on an organ; but if they ſtrike the pannel, they will find it uniſon, or octave, to that particular note.

6th. This ſympathy is not confined to inanimate nature; a dog will begin to howl at one particular note, when he is totally indifferent to the reſt of the ſeven. May not the dog and other animals have a key, as well as a drum, a tambourin, or a braſs kettle?

7th. The drum, the cochlea, and labyrinth, of the human ear, abound with fibrous nerves—too delicate and pulpy, indeed, to be capable of tenſion, like a muſical ſtring; but they muſt have great variety of diviſions, as connected with the cochlea; and the cochlea may be conſidered as a muſical inſtrument. If the interruptions in theſe nerves be in harmonic intervals (as is more than probable), may not their ſympathy with external ſounds cauſe our perception and diſcrimination of different ſounds? and may not the different formation of the cochlea, in different people, be the reaſon why ſome are bleſt with a muſical ear, and others not? The waves of the air are propagated up the meatus auditorius, and give a mechanical ſtroke, or impreſſion, to the auditory nerves; ſo that hearing may be ſaid to be a ſpecies of feeling, as a ſtroke, or impreſſion, on the eye, produces the ſenſation of light.

Every kind of elaſtic body is a conductor of ſound as well as the air. If the ear be held to one end of a long ſtick, a beam, or a fallen tree, and the ſmalleſt ſcratch be made at the other end, the ſcratch will be diſtinctly heard by the ear. But the air is the general conductor of ſound; it pervades all places, and is therefore moſt proper, as being preſent to the ear whereſoever ſituated. If a bell, *a*, fig. 9, Plate XVIII. be hung in a glaſs receiver on the air-pump, and the air exhauſted, no ſound can be heard when the bell is rung: for if it hangs ſo that the wire trigger *c*, acting through the collar of leathers *d*, can move the pin *o* (fixed to the top of the bell), the bell may be rung in vacuo as well as in the open air. This experiment proves the air a conductor of ſound. But if the bell be put in a ſtrong glaſs to which a forcing ſyringe, as fig. 12, Plate XVII. can be applied, and the air be condenſed about it, the bell rung as above will be found to increaſe in loudneſs in proportion to the condenſation.

2d. The metallic round box *a*, fig. 10, Plate XVIII. is ſcrewed cloſe to the braſs plate *b*, on the thread of the collar of leathers *c*. In the box is contained a little gunpowder, which can be ſhoved over the hole *z*, by the arm *o o*. Theſe arms are actuated by the wire *w* going through the collar of leathers *c*; ſo that, by being turned round, the gunpowder falls through the hole *z*, on the red-hot iron *x*. This being performed in vacuo, as in the laſt experiment, the inflamed powder *makes no noiſe*. But as no flame can be produced without air, it may be aſked how gunpowder can be ignited in vacuo? It carries its own air along with it; for nitre, when heated, produces more than one hundred times its bulk of vital air; and nitre is one of the principal ingredients of gunpowder. Hence the flame at *x* having no air to diſplace around it, the inflammation is ſilent; but when the air is let into the receiver, a few grains would blow up the box and plate *b* with a loud noiſe: that noiſe would be greatly increaſed if the air was condenſed round the hot iron, or the bell, in the former experiment. A bell may be heard under water tolerably well; but its pitch or key will not be the ſame as in air; it will be a fourth deeper.

As ſound travels 1142 feet, or about a quarter of a mile, in a ſecond; and as a perſon in health has about 70 pulſations or beats of the artery at the wriſt in a minute; this approaches ſo near to a quarter of a mile for every pulſation, that if the flaſh of a gun at ſea, in the night, was ſeen eight pulſations before the report was heard, the ſhip may be concluded to be about two miles off.

Spongy bodies, as woollen cloth, abſorbs ſounds; hence muſic or oratory are ill heard behind a number of people.

Different kinds of air produce different ſounds, though all nearly of the ſame loudneſs. Air preſſed from a bladder through a ſmall pipe into vital air, gives a ſound half a tone lower than when preſſed into atmoſpheric air; the ſame effect takes place when the pipe ſounds in azotic air; but when theſe two airs are mixed in the proportions they are ſaid to bear in the atmoſphere, the ſound is the ſame as in the atmoſphere. Injected in inflammable air, the ſound is ten or twelve tones higher; in fixed air, one third lower; and in different airs not uniformly mixed, intolerably harſh and diſcordant. Theſe effects ſeem to ariſe from the different weights of theſe airs. For the more denſe the medium that ſurrounds the ſounding body, the deeper is the tone; as the tone of a bell-glaſs becomes lower the more it is filled with water, or the deeper it is immerſed in it.

LECTURE VI.

HYDROSTATICS.

THIS branch of natural philoſophy treats of the action, the motion, and preſſure, of fluids in general; but the mechanical properties of water is its principal object. By obſerving that this fluid is capable of imbibing a large quantity of ſalt, ſugar, &c. without having its bulk increaſed, and that aquatic plants have round pores, it has been imagined that water is formed of round particles, touching one another (and, therefore, incompreſſible), but infinitely too ſmall to be ſeen. To make a picture of this idea, the larger balls, fig. 1, Plate XIX. repreſent water, and the ſmaller, ſalts, or other particles that can inſinuate themſelves into the pores, or interſtices, of the bigger balls. This idea is a little ſtrengthened by the different characters of water, ſuch as mineral waters, medicinal waters, and ſuch as imbibe the fine particles of ſtones in the bowels of the earth, and the particles of air from the atmoſphere; ſtript of theſe, we find the *ſimple element* the ſame in all parts of the world; and, therefore, it muſt derive its various characters from particles taken into its pores, or interſtices. One principle, however, we are ſure is united with it, and that is light, or fire, but not ſo as to be obvious to our ſenſes; it gives it fluidity, and, without increaſing its bulk, reſiſts the coheſion of its particles: hence the eaſe with which they ſlide over one another, in the fluid ſtate, and the ſolid form they aſſume when fire is detached from them. This eaſe with which the particles of water ſlide over one another, and yield to the lighteſt impreſſion, conſtitutes one of its characteriſtics as a fluid; and is the reaſon why its ſurface is ſo liable to be harrowed up into waves. It ſhews alſo how they give way, when any light body ſwims on their ſurface; and when in rapid motion how they riſe above their level when met by a ſolid, or any reſiſting body; for water is the ſlave of inertia as well as all other matter. If water, then, can be allowed to be formed of pillars of round particles, we may account for the ſwimming of lighter bodies in it; theſe bodies preſs down the pillars underneath them, and make the neighbouring ones riſe in proportion, till a balance is reſtored; ſo that if the bed made by the ſwimming body was filled with water, that water would be exactly equal in weight to that of the ſwimming body. That is to ſay, *every body that ſwims in water, juſt diſplaces ſo much water as is equal to its weight.*

I put the ſmall model of a boat *a*, fig. 3, Plate XIX. into the tub A, filled with water up to the cock *c*; the boat, by its weight, will force a quantity of water through the cock *c* into the baſon *d*. If now the boat be put in one ſcale of fig. 2, Plate XIX., and the water in *d* be poured into the other ſcale, the water and boat will be found to balance each other.

Or if the ſtick *a*, fig. 4, Plate XIX. be put in one of the above ſcales, and balanced with water in the other, and then put eaſily into the jar *c* full of water; the water it diſplaces will run over the top of the jar. If now the ſtick be taken out of the water, the vacancy it leaves in the jar will be exactly filled by the water in the ſcale.

2d. I tie a piece of bladder (a little flaccid) over the end of the open glaſs cylinder *c*, fig. 5, Plate XIX. ſo that it will hold water, and fill it up to *a b*; I then immerſe it in the veſſel *n o*, filled with water to *r s*. If then the ſurface of the water in the inner cylinder *a b* be preſſed even with the ſurface *r s*, the bladder will be flaccid, even, and horizontal, as *d e f*. But if the inner cylinder be lifted up, ſo that the ſurface *a b* ſhall be above *r s*, then will the bladder be preſſed concave downwards, as *d m f*. If then the ſurface *a b* be thruſt beneath the ſurface *r s*, the bladder will be forced convex upwards, as *d w f*. Do not theſe experiments prove that water preſſes upward, as forcibly as it weighs downward, according to its perpendicular height? For, when the two ſurfaces are even, the bladder is neither preſſed up nor down; ſhewing, that there is an agent underneath it, equal in force to the weight of water above the bladder, &c. This agent is the returning pillars of water, endeavouring to riſe to the level of the water in the outer cylinder.

3d. The action of theſe returning pillars may be better underſtood by fig. 6, Plate XIX. where *a* repreſents a glaſs cylinder, open at both ends, *b* a ſtring by which a thick piece of lead, *m*, may be held faſt to the bottom of the cylinder: to prevent the water getting in between the lead and the glaſs, the lead is firſt covered with wet leather. If then (with the cylinder in one hand, and the ſtring in the other) the lead and cylinder be plunged in the veſſel of water *c d*, to the depth of ſix or eight inches, the ſtring may be let go, and the lead will be preſſed ſo faſt to the cylinder, that no water can penetrate between them. What preſſes it?—The ſhort pillars of particles underneath it, influenced by the tall pillars *o n* and *q g*. Hence it may be ſeen how lead may ſwim, as well as veſſels that are ſpecifically heavier than water, provided they are ſo formed as to diſplace as much water as is equal to them in weight. Ships ſink when full of water, becauſe they do not in that ſtate diſplace ſo much water as is equal to their weight: when ſwimming, they do. But if the cylinder and lead were lifted up as high as *c d*, the lead would fall off, and break the outer jar, if not prevented by the ſtring. Shewing that water preſſes according to its perpendicular depth, and *that* in all directions alike; for if the ſeveral crooked open tubes, fig. 7, Plate XIX. have their upper end ſtopped by the thumb, and immerſed in a jar of water, ſo ſoon as the thumb is removed, the water will inſtantly riſe in them to the level *a c*. Or if a veſſel, fig. 8, Plate XIX. be filled with water, and the orifices *a* and *b* (bored with the ſame tool) be both opened at the ſame inſtant, they will diſcharge equal quantities in the ſame time: proving that water preſſes laterally, or ſide-wiſe, as forcibly as downwards, according to its perpendicular height.

4th. The particles of water ſliding over each other with ſuch exceſſive eaſe, it is evident that if I ſtop the end of the crooked tube, fig. 9, Plate XIX. at *a*, when full of water, the water will preſs againſt my thumb at *a*, with a force equal to the weight of water contained in the tube between its top *b* and the level with my thumb *c*; for the inſtant I remove my thumb, the water falls to the level *c a*: *n a* may therefore be conceived as one of the returning pillars that preſſed the bladder, and ſupported the lead in the ſecond and third experiments.

5th. But if, inſtead of one returning pillar, we make ſome thouſands, as in the caſe of the hydroſtatic bellows, the power becomes exceſſive with a ſmall quantity of water, fig. 10, Plate XIX. This machine is made of two ſtrong round boards united by ſtrong leather, in the manner of common bellows, but nailed ſo tight to the edges of the boards as to hold water; *a* is a pipe of any height leading into the inſide of the bellows. If water be poured into this pipe, the upper board will ſoon begin to riſe and lift the weight *w*: and if the pipe was tall, and that board wide enough, it would lift the man who poured in the water. If, when the bellows are full of water, weights were laid on them till the water was forced up to the top of the pipe *a*, thoſe weights would expreſs the weight of a pillar of water whoſe baſe was equal to the area of the under-board of the bellows, and whoſe height was from that board to the top of the pipe *a*; which may be better underſtood by the ſpotted line in the figure. It is evident from what was ſaid of the laſt experiment with the crooked tube *b c n a*, that the returning pillar *n a* would preſs as forcibly againſt the bottom *n* by reaction as the tall pillar *b n* by its weight; for the preſſure againſt the thumb *a* was equal to the weight of water between *b* and *c*, and therefore the reaction of the ſhort pillar upon *n* would be equal to the weight of the tall pillar. This reaſoning carried to the bellows will account for the weight they lift; for the water within the bellows is all returning pillars (like *n a* when the pipe *a* is full), each endeavouring to riſe to the level *e n*, and thruſting againſt the lid with a force that would bring them to that level, if they had an opportunity. But if, inſtead of the pillar of water *e o*, acting on the bellows by its weight, that water was *forced* in by a piſton moving in *e o*, the bellows, if ſtrong enough, would lift a houſe! On this principle a preſs is formed of immenſe power. Fig. 10, Plate XIX. *a* is a ſtrong caſt-iron cylinder, ground duly circular within; *e* is a piſton fitting very tight into the cylinder; *c* is the piſton of a force and a ſucking pump, which, by its aſcent, draws the water out of the ciſtern *d* through the valve *n*; by its deſcent the valve *n* ſhuts, and the water above it is forced through the valve *o* into the cylinder *a*, and drives up the piſton *e*; this forms a preſſure at *m*, by the force of one man working at *s*, that ſqueezes cotton bags, hay, &c. into twenty times leſs compaſs than they generally occupy. Thus if water can inſinuate itſelf but the thickneſs of a ſhilling under a bank, dam, &c. and has communication with a tall pillar of water, the banks of canals are blown up as if a train of gunpowder was fired under them. But if water cannot get in between two ſurfaces, it will then preſs a light body to the bottom of the containing veſſel, and prevent its ſwimming. The cork *a*, fig. 11, Plate XIX. if fixed to an even piece of thin glaſs, and laid on the even bottom of the veſſel A, it will lie there when the veſſel is full of water. Suppoſe *a*, fig. 13, Plate XIX. a ſection of the bed of a river, and *c* a land-drain under or through one of its banks; compare the tall columns of water *d e* to the ſhort ones in the drain, and it will be eaſy to conceive, that if the part of the bank *g* be not as heavy as the columns *d e* (as water preſſes in all directions alike according to its perpendicular height), that part of the bank will blow up. This effect is prevented by *puddling*, as it is called; that is, cutting a trench lengthwiſe of the ditch, about eighteen inches wide, and a little deeper than the canal, or reſervoir, as *n m*; this is filled by a little at a time with clay, or common earth, in a ſemifluid ſtate by water; when the firſt is nearly dry, a little more is poured in, and ſo on till it is filled: this makes ponds, ditches, canals, docks, or reſervoirs, as ſtaunch as a bottle.

6th. The hydroſtatic paradox, as it is called, may alſo help to illuſtrate this doctrine. A braſs cylinder, of which *a b*, fig. 14, Plate XIX. is a ſection, has a piſton *c*, that fits it ſo that it can eaſily move up and down in the cylinder by the rod *d*; *e f* is a cylinder of glaſs, cemented into the braſs collar *g h*, and ſcrewed on the braſs cylinder. The balance being now applied to the chain part of the rod *d*, the whole is filled full of water; but as part of the water will be loſt at the piſton *c*, and paſs through the hole *q* (for the piſton muſt not be water-tight, as its friction would hurt any concluſions that could be drawn from the experiment), water muſt be kept eaſily pouring in, while the column is having its exact weight aſcertained in the ſcale of the balance. When this is exactly done, the glaſs cylinder is unſcrewed from the braſs cylinder, and the conical glaſs A ſcrewed in its place, fig. 15, Plate XIX.: this glaſs is exactly the ſame height as the cylinder *e f*, but will hold ten times as much water: ſhould it not then weigh ten times as much on the plug *c*?—Yes, it would, if it were frozen, for then the whole would be lifted. But the ſame weights which lifted the column contained in *e f* will lift the water in A; but not all the water: it will lift only the column *r s t u* through the middle of it; or rather a column whoſe baſe is the piſton *c*: the reſt of the water in A is ſuſtained by this pillar and the flanging ſide of the conical veſſel. In reality, then, there was no more water on the piſton in the ſecond than was in the firſt experiment. But will it not appear ſtill more paradoxical, if the water that can be contained in the ſmall pipe B, fig. 16, Plate XIX. ſhall form as great a preſſure on the piſton *c* as all the water that was upon it in the laſt experiment?—It is even ſo. Let the cap *z o* be ſcrewed in the place *g h*, and the rod *d* paſs through the ſmall tube B; if now it be filled with water, the weights will be overcome, and the piſton forced down exactly as in the laſt experiments: this is done by the returning pillars within the braſs cylinder *a b*, fig. 14, Plate XIX. preſſing againſt the lid *z o*; for as action and reaction are equal, and contrary, with what force ſoever the ſhort pillars preſs againſt the lid *z o*, they will react with the ſame force againſt the piſton *c*. Now theſe ſhort pillars are all influenced by the tall pillar of water in B, and would all riſe up to the top of B, if not ſtopped by the lid *z o*, then would they act by their weight inſtead of their preſſure, as in the firſt experiment. This ſeeming paradox may be further aggravated by inverting the conical veſſel A, fig. 15, Plate XIX. as fig. 17, Plate XIX.; in which caſe we affirm there is as great a preſſure on the bottom *a b*, as would be if the whole cylinder *a b c d* was filled with water. We muſt ſtill keep in mind the nature of fluidity; that its particles ſlide with the utmoſt eaſe in all directions accordingly as they are preſſed; conſider then (as in the laſt experiment) the influence the long pillar *h n g e* will have upon the ſhort ones, ſuch as *z y*, *o r*, &c.; that theſe will be preſſed againſt the ſloping ſide with a force that would raiſe them to the height of the tall pillar, if that ſide did not ſtop them; and, conſequently, that they will have a reaction againſt the bottom equal to the gravity of the tall pillars. The preſſure of the water, therefore, differs from its gravity in this reſpect: the gravity of water is according to its quantity; the preſſure of water is according to its perpendicular height: this preſſure is independent of quantity; a pipe ſix feet high, and one inch in diameter, would be as liable to be burſt as a cylinder of ſix feet high and ſix feet diameter, equally ſtrong.

7th. This preſſure increaſing like the acceleration of falling bodies, is a beautiful inſtance of that ſameneſs and ſimplicity obſervable through all the laws of nature; it is as the odd numbers 1, 3, 5, 7, 9, 11, &c.; that is, if fig. 1, Plate XX. repreſent a tall ſquare veſſel full of water, five inches deep, and one inch ſquare, the preſſure againſt one of the ſides of the topmoſt inch will be nearly one ounce; againſt the ſame quantity of ſurface below, *three* ounces; againſt the inch below, *five* ounces, &c. Now this is as the ſquare of the depth; i. e. againſt the two upper ſurfaces there is a preſſure of *four*; againſt three of the upper ſurfaces there is a preſſure of *nine*; againſt four of the uppermoſt ſurfaces there is a preſſure of *ſixteen*; and againſt the whole front ſurface, five, there is a preſſure of *twenty-five*; for 9, 7, 5, 3, 1, added together, will make 25, and five times five is twenty-five. This may be proved by a ſimple machine, fig. 2, Plate XX. made of the ſame height as the laſt. The two pieces of inch-board *a* and *b* are mortiſed into one another, and have grooves at an inch diſtance, to receive two panes of flat window glaſs, which are made water tight with putty in the frames *a* and *b*. A thin board, *c*, hangs by two hinges on the corners of the two panes at *n*, and covers the edges of the panes to the bottom. This board is held to the edges of the two panes by the weight *w*, and is covered with cloth to hold water. Now as the machine is open at top between *n* and *m*, water may be poured in there; and, if one ounce is hung at *w*, the door *c* will be forced from the edges of the glaſs when the water riſes to the line 1. If four ounces are hung at *w*, the door will be opened, and the weight lifted, when the water riſes to the line 2. If nine ounces be hung at *w*, the water will preſs off the door when it riſes to the line 3, &c. ſhewing that the preſſure is as the ſquare of the depth; and giving a rule by which may be eſtimated the preſſure of water againſt embankments, flood-gates, reſervoirs, &c. and alſo demonſtrating, that if water were twice as high on one ſide of a flood-gate as on the other, the preſſure would be four times as great: alſo, that the ſide of a ciſtern is as forcibly preſſed as the gate of a large dock, if the perpendicular height of the water, and the area of the ſurface preſſed againſt, be the ſame.

8th. Spouting pipes are ſubject to the ſame law. Pipes of the ſame length and bore diſcharge water according to the ſquare root of the depth beneath the ſurface; i. e. the pipe *b*, in fig. 1, Plate XX., will diſcharge twice the quantity in the ſame time as the pipe *a*, though bored with the ſame inſtrument, being four times as far below the ſurface. One, nine times as far beneath the ſurface, would diſcharge three times as much water, in the ſame time, as the pipe *a*, &c. the veſſel being kept full.

9th. The law by which a head of water will force water through pipes of equal bore, at different heights, is another inſtance of the mathematical uniformity of nature. Let *a b*, fig. 4, Plate XX. repreſent a tall pillar of water, whoſe head at *a* muſt be kept to that level during the experiments. On the middle of this pillar, place one leg of a pair of compaſſes, and draw a ſemicircle, whoſe diameter is the height of the pillar of water. It is remarkable that the pipes both above and below the middle will throw water to an horizontal diſtance proportionate to the ſines of this arch; i. e. the ſine *c d* is equal to the ſine *g h*, and their reſpective pipes throw water to the ſame diſtance. The radius *i k* may be conſidered as the longeſt ſine of an arch, and its pipe will accordingly throw water to the greateſt horizontal diſtance of any ſimilar pipe that could be fixed in any part of the pillar between *a* and *b*. The water being ſtill kept up to the level of *a*, if the three pipes *n*, *m*, and *o*, be opened at bottom—*o* making an angle with the horizon equal to 22° 30′; *m*, an angle equal to 45°; and *n*, equal to 67° 30′—they will each throw water to an height according to their reſpective ſines; i. e. the pipe *o*, to *h*; the pipe *m*, to *k*; and the pipe *n*, to *d*: their horizontal diſtance alſo will exhibit a wonderful conformity: the water that touches the ſine *g h*, and that which touches the ſine *c d*, fall at the ſame place with the waters of the pipes *c* and *g*; and that which touches the longeſt ſine *i k* ſpouts to the greateſt diſtance, and falls at the ſame place with water from the pipe *i*. Hence a mortar, or great gun, elevated to an angle of 45°, will throw a ball to a greater horizontal diſtance than it will in any other angle. This is theoretically true, but not quite practically ſo; for wind, a greater or leſs denſity in the air, &c. will make a ſmall difference; and ſo it will in the ſpouting fluids; the common reſiſtance of the air making each parabola a little more perpendicular on its right-hand ſide than on its left.

10. The reſiſtance of the air is alſo the reaſon why water will not riſe ſo high in a jet as in a tube. Fig 3, Plate XX. is the laſt-uſed pillar full of water; if a ſmall pipe *c* be opened, the water will riſe only to *a* in the character of a jet, but it will riſe to the level *d* in the tube *t*; and let that tube be inclined in any angle, the water will riſe to the level *d*, if the tube be long enough; or, in caſe the pillar was empty, and water was poured into the tube *t*, the water in the pillar would keep on a level with the water in the tube: ſhewing that fluids univerſally will riſe to a level, let the pipes of conduct be long, ſhort, ſquare, round, big, little, or crooked. Why does not ſo heavy a body of water as is contained in the pillar force up ſo light a body as is contained in the tube higher than the level?—Gravity, and the flexibility of the preſſure

in the fluid, accounts for this. If no tube were joined to the pillar, the water would be at reſt, and held quiet in it, by the power of gravity; but now we join the tube *t* to it, and open the ſtop-cock *e*; inſtantly the fluid becomes leſs preſſed at this opening, than by the ſides of the pillar, and the particles ſliding over one another with ſuch eaſe, the weight of the water in the pillar will ſqueeze up that in the tube to its level. But why not higher?—Becauſe, in reality, it is but a column of water in the pillar, of the ſame thickneſs as the tube, that can operate upon the water in the tube; all the reſt of the water is ſupported by the bottom of the pillar, and the projecting reſervoir at top; ſo that it is but the effect of an inverted ſyphon, and may be repreſented by an imaginary pillar going through the water, and joining to the tube *t*, making the ſyphon *d e t*.

11. Water thus riſing to its level, affords us a means of conveying it acroſs valleys without thoſe expenſive aqueducts erected by the ancients for that purpoſe, whoſe ruins remain the wonder of our own times. A pipe, conforming to the ſhape of the valley, will anſwer every purpoſe of an aqueduct. Suppoſe the ſpring at *a*, fig. 5, Plate XX., and I want its water on the other ſide of the valley D; it is evident, from what has juſt been proved, that a pipe of lead, or iron, laid from the ſpring-head acroſs the valley, will convey the water up to the level of the ſpring-head; but, by a ſurvey, I find the houſe rather lower; a conſtant ſtream will, therefore, pour into my ciſterns and ponds, as if my houſe were on the other ſide of the valley. In this caſe a regard muſt be had to the depth of the valley; for as the preſſure of water increaſes in the rapid ratio of 1, 3, 5, 7, &c. if the valley be deep, the pipes muſt be made very ſtrong near its bottom, or they will burſt.

Of Specific Gravities.]—The ſpecific gravity of a body is its weight, when compared with the weight of its bulk of clear rain-water. The ſpecific gravity of quickſilver is ſaid to be fourteen; becauſe a cubical inch of quickſilver, put in one ſcale of a balance, would require fourteen cubical inches of water in the other to balance it. So the ſpecific gravity of copper is eight, becauſe one cubical inch of copper will balance eight of water. The denſity of bodies, therefore, compoſes their ſpecific gravity, as may be better exemplified by three cubical inches of wood of different denſity; one will ſwim a-top, another ſink to the bottom, and another remain at reſt in any part of the water: the firſt, then, is ſaid to be ſpecifically lighter; the ſecond, ſpecifically heavier; and the third, of the ſame ſpecific gravity as water. Water being thus made the ſtandard of compariſon, reſpecting the denſity of different bodies, a table may be made of the different ſubſtances in nature compared with water, with one another, and with themſelves. See Table of Specific Gravities, fig. 3, Plate XXIV.

It may be ſeen in the table, that there is great variety of denſity in bodies that bear the ſame name. Glaſs, for inſtance, is above twice as heavy as its bulk of water; ſome three times as heavy; and ſome almoſt four times. Cobalt has great variety; ſome is ſix, and ſome eight, times as heavy as its bulk of water. Diamonds have no variety; zinc and lead very little; ſterling gold is ſeventeen and three quarters heavier than water; and pure gold from nineteen to twenty times heavier.

As one cubit foot of pure water is equal to 1000 ounces avoirdupoiſe, this becomes a ſtandard for finding the ſpecific gravity of bodies, whether heavier or lighter than water.

It having been already proved, that every thing that ſwims in a fluid juſt diſplaces ſo much of that fluid as is equal to its weight; on this axiom is founded an inſtrument called the *hydrometer*, for meaſuring the ſpecific gravity of fluids. This is generally an egg-like bulb of glaſs, ivory, or copper, with a thin graduated ſtem, made ſmall a-top to receive a weight *g*, which will ſink the hydrometer to a certain depth in proof ſpirits, as fig. 7, Plate XXIV. Now a proof ſpirit is generally ſuppoſed to be one-half of its weight a pure ſpirit, or alcohol, that, if ſet on fire, would all burn away; and the other half water: or, that one gallon of it ſhould weigh ſeven pounds twelve ounces, when the thermometer ſtands at 55°. As bodies that would ſwim in water, would ſink in ſpirit of wine, the weight *g* ſhould be filed, or diminiſhed, till it ſinks the hydrometer to the middle of the ſtem; and figures above and below that middle ſhould denote how much the compound is above or below proof: for if it is below proof, that is, if it has more water than ſpirit, its buoyancy will be too much, and the proof-mark will be thruſt above the ſurface; if above proof, the mark will ſink below the ſurface: and in both caſes, to figures that ſhould indicate how much water, or ſpirit, there is, more than the ſtandard. But though this inſtrument is founded on philoſophical principles, it is liable to much fallacy. For, in the firſt place, ſpirits and water form a very different penetration with each other, at one ſtage of their mixture, to what they do at another. A pint of water, added to a pint of water, will make a quart; and a pint of ſpirit, put to a pint of ſpirit, will make a quart; but a pint of ſpirit, mixed with a pint of water, will not make a quart. See Hydrometrical Table, Plate XXV. 2d. Rum or brandy, when warm, will ſink the hydrometer, and appear ſtronger than they are: in extreme cold, or when mixed with a little ſugar, they will appear weaker than they really are, &c. &c.

In this table may be ſeen how ſpirits and water penetrate each other in every ſtage of their mixture. The upright, or perpendicular ſcale, ſhews the ſpecific gravity of the ſpirits, water being called 1000, and alcohol 830. The horizontal ſcale a-top ſerves to determine how many gallons of water there are in 100 gallons of the mixture; and the curvilinear line, or ſcale, indicates the ſtrength of the ſpirits, with reſpect to that ſtandard called proof. For example: A ſpirit, whoſe ſpecific gravity is 900, is compoſed of about twenty-eight parts of water, and ſeventy-two parts alcohol; or in 100 gallons of ſuch ſpirit there is twenty-eight gallons of water, and that it is twenty-two gallons in 100 above proof, as indicated on the curvilinear ſcale.

This ſcale being founded on experiment, an hydrometer ſcale is formed from it, as ſeen on the right-hand of the plate, where only part of the bulb can be ſeen. This ſcale is made from trials, in which 100 parts of pure alcohol, and 100 parts of water, were mixed in this proportion, viz. ninety-nine parts of water, and one of alcohol, ſunk the hydrometer to the firſt diviſion of the ſcale; ninety parts of ſpirit, and ten of water, ſunk it to the ninetieth diviſion; ten parts of ſpirit, and ninety of water, ſunk it to the tenth diviſion, &c. &c.

It is curious to obſerve how different the penetration of the two fluids is at different ſtages of this admixture; as, for example, between the ſpirit-diviſion of twenty and thirty, and the water diviſion between twenty and thirty. It may be ſeen alſo, that when there are between twenty and thirty parts of ſpirit, mixt between ſeventy and eighty parts of water, that the two fluids form a more intimate union, and occupy leſs ſpace than in any other proportion. Can the equal diviſions, therefore, of the common hydrometer be true?

2d. I fill the bottle *a*, fig. 6, Plate XXI. with water, and placing my finger on its mouth, invert it in a glaſs of red wine. The wine (containing ſpirit) is ſpecifically lighter than the water; ſo the heavy water deſcends into the glaſs, while the light wine riſes to the top of the bottle in beautifully ſtriated threads.

3d. Smoke riſes in a chimney by the ſame law; though, of itſelf, it is only lighter than air while it is warm, and, therefore, riſes little in the open air, and its groſs parts ſoon precipitate back to the earth: it is heated air that carries ſmoke with ſuch rapidity up a chimney. Fire heats the air on all ſides, and ſets its particles at an increaſed diſtance; hence the volume of air near a fire becomes ſpecifically lighter than the colder air at a diſtance, and is by it buoyed up into the atmoſphere. The heated air in a chimney, therefore, makes the pillar, of which it is a part, lighter than the pillars of air at a diſtance. The heavier pillars, as *a*, fig. 1, Plate XXI. ruſh, therefore, through the fire to reſtore an equilibrium, and becoming rarefied themſelves, are forced up the chimney by ſucceeding pillars: ſo that a perpetual current continues up the chimney ſo long as the fire continues, and becomes an uſeful ventilator for the room.

4th. Few land animals ſeem ſo helpleſs in the water as the human race; yet fleſh and bones, and altogether, we are ſpecifically lighter than water; but ſo little, that, except we can lay with the face upwards, and have the mouth and noſe *only* out of the water, we muſt make ſome effort to keep ourſelves from ſinking.

In our uſual mode of ſwimming we do not diſplace ſo much water as is equal to our weight, and are, therefore, under the neceſſity of turning our hands and feet into fins, to keep on the ſurface: in the exertion of ſwimming, we force too much of the body out of the water, and exhauſt our ſtrength in keeping it ſo. A ſhip water-logged, or nearly full of water, requires little pumping to keep her from ſinking, the water within and without being ſo near upon a level; but when ſhe ſprings a leak near the bottom, the preſſure there is ſo great in compariſon of what it is at the ſurface within the ſhip, that ſometimes a whole crew cannot pump the water out as faſt as it is preſſed in. A man ſwimming is much in the ſame predicament; when he lies near the ſurface, the preſſure upwards under his body is ſo much greater than the weight of water over his body, that being wholly immerſed, he floats like a log, without any exertion; but if he dives a few yards beneath the ſurface, he will find difficulty in aſcending, for in that ſituation (and ſo in proportion to the depth he dives) the preſſure upon, and underneath, his body, will approach nearer and nearer to an equality; and as his fleſh and ribs are capable of being ſqueezed into leſs compaſs than they naturally poſſeſs, the exceſſive preſſure of water, at a certain depth, will force his body into leſs bulk than its bulk of water: being thus ſpecifically heavier, and that weight increaſed by the water forced into his ſtomach, and the pores of his ſkin, he ſinks to the bottom. If a perſon ſinks ſlowly into water, a little effort will bring him back to the ſurface; but if then he does not throw himſelf on his back, and ſink his head, but with violent ſtruggling lifts himſelf ſo much out of the water as not to diſplace ſo much of it as is equal to his weight, he ſinks accelerated: with much effort he may bring himſelf up again; but in making this unhappy voyage ſeveral times, his ſtrength fails, he ſwallows much water, and then becomes heavier than the fluid.

Immerſe a bladder, with a little air in it, in the pillar of water *a b*, fig. 4, Plate XX.; hang weights to it, ſo that it will juſt riſe when thruſt ſo far beneath the ſurface as *y*: if it be then thruſt down as low as *z*, it will ſink; for as the preſſure of water increaſes in ſo ſwift a ratio as 1, 3, 5, 7, &c. it is evident that there is a greater difference (though not numerically) in the preſſure of the depth between 1 and 3, than there is between 5 and 7, or 13 and 15, &c. for if a man near the ſurface of water has a force of 3 preſſing upwards under him, and but a force of 1 preſſing upon him, he will certainly have leſs preſſure on his body than if 19 was preſſing on, and 21 under, his body. For ſo great is the preſſure of water at great depths, that if a bottle be corked ever ſo tight, and let down twenty or thirty fathom into the ſea; the cork will be forced into the bottle. So if water is prevented from exerting its upward preſſure upon a body, that body will be held down by the water upon it.

Hydroſtatic Balance.

Every body, heavier than its bulk of water, loſes ſo much of its weight, by being ſuſpended in water, as is equal to the weight of its bulk of water.

This uſeful axiom was diſcovered by the celebrated Archimedes; when, by the immerſion of his body in a bath, he conceived the hint by which he detected the alloy in king Hiero's crown. He ſuſpended the crown at one end of a ſcale-beam, and as much pure gold at the other as balanced it: now, ſaid he, there is an equal number of particles at one end of the ſcale-beam as at the other (ſuppoſing the ſeparate particles of all matter of the ſame weight); but if you, Mr. Crown-maker, have mixed the pure gold with ſilver, or copper, the crown will be bigger than it ought to be (ſee Table of Specific Gravities), and, of courſe, more buoyed up in water. On the immerſion of the crown in one veſſel of water, and the pure gold in another, it was found to be ſo.

1ſt. I hang the conical piece of lead *a*, fig. 2, Plate XXI. at one end of a ſcale-beam; and a braſs conical bucket at the other, which the lead *a* exactly fits. I fill this bucket with water, and put weights in the ſcale under it, till the lead *a* is balanced. If now I immerſe the lead in a jar of water, that end of the ſcale-beam inſtantly riſes, and ſhews the lead to have loſt ſome of its weight: but the axiom affirms, that every heavy body, ſuſpended in water, loſes ſo much of its weight as is equal to the weight of its bulk of water: now I have its exact bulk of water in the oppoſite ſcale; I pour this out, and an equilibrium in the balance is inſtantly reſtored.

2d. But ſuppoſe I wanted to know how much the lead was heavier than its bulk of water; or, its ſpecific gravity. In this caſe I muſt weigh it, both in air and water. I find the lead weighs in air fifty-five ounces; but when it is hung in water, I find it requires five ounces to bring it to an equal balance; or, according to the laſt experiment, five ounces is the weight of its bulk of water; then ſo many times as five ounces are contained in fifty-five ounces, ſo many times is the lead heavier than its bulk of water, viz. eleven times, which is the ſpecific gravity of lead.

3d. I have a ſilver candleſtick, which I ſuſpect not to be genuine ſilver. It weighs in air twenty-two ounces; but on being immerſed in water (hung by a ſmall thread), I find it loſes 2.1 ounces; then 2.1 ounces is the weight of its bulk of water. But 2.1 ounces is contained in twenty-two ounces 10.4 times. Good ſilver is a little more than ten times as heavy as its bulk of water, therefore I become ſatisfied with my candleſtick.

4th. A new guinea ſhould weigh 129 grains; but it may weigh ſo much and be made of ſilver, copper, tin, &c. and have no more gold than a mere coat to cover it; but, in all thoſe caſes, it will be too big, and, by that means, loſe too much weight in water; for ſterling gold ſhould be 17.793, or ſeventeen times and three-fourths as heavy as its bulk of water: and in order to try its purity by water, the hydroſtatic balance has generally nippers and buckets to hold bodies to be weighed in water; but in this, as well as moſt caſes, a horſe-hair will anſwer very well, being very ſtrong, for the ſmall ſpace it occupies in the water. A loop in this hair will hold the guinea; and being ſuſpended on a light ſcale-beam, it may be weighed in air, and found, probably, to weigh 129 grains. If, then, it be ſuſpended in water, fig. 4, Plate XXI. its loſs of weight may be ſeven grains and a quarter, by which, if 129 grains be divided, the quotient will be ſeventeen and three quarters, the ſpecific gravity of the guinea, which is thus found to be a very good one.

5th. A ſuſpended guinea may have full weight in air; it is immerſed in water, and loſes eight grains of its weight. This, then, is not ſterling gold: for eight contained in 129 is only ſixteen times; and it ought to have been ſeventeen and three quarters.

6th. Hence the alloy of ſuch adulterated coin may be calculated pretty nearly by this method. Suppoſe a maſs of metal, containing equal weights of gold and ſilver, was equal to the weight of two guineas, i. e. the gold was equal to 129 grains, and the ſilver part of the maſs equal to 129 grains; then, together, the maſs would weigh 258 grains. The gold (proved as above) would loſe in water ſeven grains and a quarter, and the ſilver twelve grains and a half, together nineteen grains and three quarters; the 258 grains divided (as above) by nineteen and a quarter, would give thirteen as the ſpecific gravity of the compound maſs.

7th. If a guinea be adulterated with copper in a proportion of one to four, the maſs may be conſidered as five grains. If five grains contain one grain of copper, what will 129 grains (the weight of the guinea) contain?—It will contain 25.8 grains. The guinea muſt therefore contain 103.2 grains of gold, and 25.8 grains of copper. What then is the ſpecific gravity of this guinea?

103.2 grains of gold would loſe in water 5.5 grains,
25.8 grains of copper would loſe in water 3. grains,

129 weight of the guinea, loſing 8.5 grains
in water, would ſhew that 129 divided by 8.5, gives a quotient of about fifteen for the ſpecific gravity of this guinea, inſtead of ſeventeen and three quarters; thus ſhewing its baſeneſs.

8th. This baſeneſs is pretty nearly calculated at the rate of 2.1 for every deficient grain; ſo that the laſt guinea would be really worth no more than about thirteen ſhillings, and yet the eye could not well detect the alloy. If the adulteration was with ſilver, each deficient grain ſhould be valued at nearly four ſhillings. But as copper is the moſt general counterfeit, with a little ſilver mixed, about three allowed for every grain is near an average.

To find the ſpecific gravity of bodies that are lighter than water, it muſt firſt be conſidered, that bodies riſe in air, water, or any other fluid, not by their poſitive levity, but by the greater denſity of the medium in which they are immerſed. This piece of cork riſes in water, becauſe it is bulk for bulk lighter than water: but I want to know how much. I therefore ſtick the cork on the hook of the ſmall ſcale *a*, fig. 4, Plate XXI. and balancing it in the oppoſite ſcale, I find it weigh thirty grains. Now, to force it into the water, I put weights in the ſcale *a*, till the cork is all immerſed; the weights neceſſary to do this, I find to be 150 grains. This 150 grains, and the thirty, its aërial weight, together, is the weight of its bulk of water, viz. 180 grains. The ſpecific gravity of the cork, therefore, is as the weight of its bulk of water to its weight in air; or (as in the heavy bodies), to divide its weight in air, by the weight of its bulk of water, will give its ſpecific gravity; thirty, therefore, divided by 180, will give 166, ſhewing the cork to be about ſix times lighter than water.

2d. I have two beams of deal timber to float down the river, containing ſeventy-five cubical feet: will this raft ſupport a man to guide it? I take eight cubical inches of this wood, and ſtick it to the hook *a*, fig. 4, Plate XXI. and find it weighs, in air, four ounces; immerſed in water, I find it requires half an ounce in the ſcale *a* to ſink it; therefore four, its weight in air, divided by the weight of its bulk of water, 4.5, will give 88 for its ſpecific gravity, ſo that it is not one fifth lighter than its bulk of water. But a cubic foot of diſtilled water, or clear rain water, weighs in air 1000 ounces; and if eight cubical inches of wood weigh four ounces in air, 1728 (the number of cubic inches in a cubic foot) will weigh 864 ounces; which, if taken from 1000, will leave 136 ounces, that a cubic foot of this wood is lighter than a cubic foot of water. Hence, 75 times 136 would give 10,200 ounces, or 637 pounds, that the whole raft would be lighter than water, ſo that it would carry the man and his wife and children. This calculation muſt be admitted under certain modifications; wood ſoaked in water will grow heavier (therefore, experiments made on porous ſubſtances muſt be made as quick as poſſible); and water is lighter in hot than in cold weather, &c. &c.

To find the ſpecific gravity of fluids. This might be eaſily done by weighing a given quantity of the fluid againſt an equal quantity of water: but the fact of a ſolid body loſing ſo much of its weight in water, as is equal to the weight of its bulk of water, dictates a more elegant way of aſcertaining what proportion any fluid bears to its weight of water. This ſolid is generally a conical piece of ſolid glaſs, as fig. 3, Plate XXI. ſuſpended from the ſcale *a*, fig. 4, Plate XXI. by a horſe-hair: ſuppoſe its weight to be 1236 grains in air; and that it loſes 412 in water; then 412 grains muſt be taken out of the weight ſcale to bring the balance even, when the glaſs is hanging in the water. The apparatus is now ready for buſineſs; and if the fluid to be eſtimated be heavier than water, the ſolid glaſs will riſe in it; if lighter, the glaſs will ſink in it: ſo that the difference muſt be added or ſubtracted, as one or other is the caſe.

1ſt. The glaſs ſolid being now taken out of the water and immerſed in brandy, it will be found to ſink in it, and to require forty grains to bring the balance level: therefore the forty taken from 412, leaves 372; indicating, that the proportional weight of this brandy to water is as 372 to 412: or, that it is about one tenth lighter than water.

2d. The glaſs ſolid being now immerſed in rectified ſpirit of wine, it balanced ſeventy-four grains more than in water; which being taken from the 412, leaves 338: the weight then of this ſpirit, in proportion to water, is as 338 to 412; or, if the weight in water, 412, be divided by ſeventy-four, the quotient will be 5.5, ſhewing the ſpirit to be rather leſs than one ſixth lighter than water. If water be eſtimated 1, the ſtandard ſpecific gravity of proof ſpirit is 9.3, to which the glaſs ſolid is eaſily adapted. But water and ſpirit forming a different penetration at different ſtages of their mixture, and alſo letting looſe a little of their ſpecific fire at the inſtant they are mixed (and growing warm), the compound ſhould ſtand ſome time before the trial.

3d. If it be required to find how much ſea-water is heavier than rain-water, immerſe the glaſs ſolid in it, and it will be buoyed up ſo that ten grains will be required to bring the balance even; ten added to 412 will make ſea-water to rain-water as 422 to 412. Or 412 divided by the additional weight, ten, will give forty-one; ſhewing that it is rather more than the one-fortieth part heavier than rain-water, bulk for bulk.

On the Diver's-bell.—This machine is founded on the principle, that air being a body, it excludes all other bodies from the place it poſſeſſes. If a bell-glaſs be preſſed into water, with its mouth downward, the air in the glaſs will drive the water down before it, and very little will enter the bell. Availing himſelf of this principle, Dr. Halley conſtructed a bell of copper, three feet diameter a-top, five at bottom, and eight feet high; loaded at bottom with ſuch a quantity of lead as to make the whole ſpecifically heavier than its bulk of water. The divers were enlightened by a ſtrong glaſs fixed in its top; and a ſtop-cock there, let out the heated air. This bell was lowered from the yard-arm of a ſhip, with two men in it, to the depth of ten fathoms. In their deſcent, they found the water riſe a little in the bell; the air about them condenſed; and thereby a diſagreeable preſſure formed on every part of their bodies, particularly at their ears, which ſeemed as if quills were thruſt into them. They had light enough to ſee the pebbles at bottom, but it appeared red light, on every thing capable of reflecting it; the red part of light being the only part capable of forcing its way through reſiſting or muddy mediums. The air preſſing through the pores of their ſkin, ſoon became as denſe within their bodies as without, when the ſenſe of preſſure ceaſed, and they found no difficulty in remaining at bottom ſeveral hours, where all was ſtill and tranquil, though the ſurface was agitated with wind. Two barrels filled with air were alternately ſent down to them, and the heated contaminated air was let out, by the ſtop-cock, at the top of the bell. This bell, however, proved fatal to two men in the Bay of Dublin, by that contraction which ropes ſuffer in being wet: this cauſed the bell to turn round in its deſcent, and entangle the ſtrings by which the divers meant to ring bells, and indicate their wants to the people on board the ſhip from whence they were lowered. Waiting too long for theſe ſignals, the bell was raiſed, and the divers were both found dead; but not drowned; they died like the unhappy people in the hole at Calcutta, by breathing contaminated air. (See Lecture on Air.)

Being applied to, to give a deſign for a bell, to go down upon the ſame wreck, I recommended a conical tub of wood, three feet diameter at bottom, two and a half at top, and three feet high; ſo loaded with lead, at bottom, as juſt to ſink of itſelf; with a ſmall ſeat for the diver, fig. 5, Plate XXI.: a bent metal tube was attached to the in and out-ſide of the bell, as *a b c*, with a ſtop-cock at *a*; and a flexible leathern tube or hoſe to the other end at *c*; this tube terminated in a forcing air-pump, faſtened to the ſide of the ſhip: *d* is a ſolid piſton, actuated by the lever *e*; upon the piſton being drawn up, the air ruſhes in at the valve *g*, and fills the ſpace *n*; on its deſcent, the valve *g* ſhuts, and the conical valve *o* opens, and lets the air be forced down the hoſe into the bell: this pump kept working, while the diver, by opening and ſhutting the ſtop-cock, is abundantly ſupplied with freſh air, and the vitiated part is forced out at the bottom of the bell. With this bell on his head, he can walk about ſeveral yards in a perpendicular poſture; and having more eaſy acceſs to pieces of wreck than in a more cumbrous bell, can faſten ropes to them, and perform any buſineſs nearly as well as on dry land. The greateſt part of the wreck ſaved from the rich ſhip Belgioſo was taken up by means of this bell.

As the diver had plenty of air to ſpare, he thought a candle might be ſupported in the bell, and he could deſcend by night. He made the experiment, and preſently found himſelf ſurrounded by fiſh, ſome very large, and many ſuch as he had never ſeen before; they ſported about the bell, and ſmelt at his legs as they hung in the water: this rather alarmed him, for he was not ſure but ſome of the larger might take a fancy to him; he, therefore, rang his bell to be taken up, and the fiſh accompanied him, with much good-nature, to the ſurface.

Mr. Smeaton's diving-bell at Ramſgate was of caſt-iron, 50 cwt. ſo that it was heavy enough to ſink of itſelf. Its ſhape was a parallelopiped, 4½ feet long, 3 wide, and 4½ feet high, ſo that two men could work under it, and could ſee, by four ſtrong glaſs lights at top. It was ſupplied with air in a ſimilar manner to the laſt.

Hydraulics.—As hydroſtatics inſtruct us in the action, the motion, and preſſure of fluids, ſo hydraulics apply theſe powers to mills, engines, pumps, pipes, canals, &c. When water is applied to mills, it is always found to act more powerfully by its weight than by its preſſure; i. e. an overſhot-wheel has always more power than when the ſame quantity of water, and of the ſame perpendicular height, acts againſt, or under, the wheel. But where velocity is wanted more than great power, the underſhot-wheel anſwers for carrying forge hammers, rolling hot iron, or any thing where diſpatch is indiſpenſable. On the overſhot-wheel the water ought to fall about 5° over the perpendicular diameter to have its greateſt power; and in the underſhot-wheel, ſo ſtrike the pedals at an angle of 45° below the horizontal diameter of the wheel, being directed to that place by a ſluice inclining 45°; the water moving over a ſmooth bottom and ſides, to have as little friction as poſſible. When water deſcends on a ſmall overſhot-wheel with greater rapidity than quantity, it is neceſſary to have a wide wheel, and an oblong aperture in the bottom of the penſtock to deliver the water. The apertures that deliver water, if round, deliver it as the ſquares of their diameters; i. e. a hole twice the diameter of another will deliver four times the quantity of water in the ſame time, their perpendicular heights being alſo the ſame; and one, three times the diameter of another, will deliver nine times the quantity in the ſame time, &c. And as the velocity with which water ſpouts from an aperture either in the ſide or bottom of a reſervoir, or veſſel, is the ſame as the ſpeed with which a body let fall in air would acquire in deſcending the height between the ſurface and the aperture; it follows, that water flows through holes agreeably to the odd numbers 1, 3, 5, 7, 9, &c. i. e. if into a tall pipe filled with water I could make a puncture where I pleaſed, as, for inſtance, at the depth of one foot below the ſurface, and it diſcharged 36 cubic inches in a minute; if that hole was ſtopped up, and I make another of the ſame diameter three feet below that, the hole would diſcharge 72 cubic inches in a minute; if then I remove it five feet below that, the ſame hole would diſcharge 108 cubic inches in a minute, &c.; being as the ſquare root of the height from the ſurface to the aperture: i. e. at the depth of four feet the hole diſcharged twice the quantity as at one foot; and at nine feet deep thrice the quantity, &c.; the water being kept at the ſame height in the tall pipe. A ſmall allowance muſt be made for the friction and eddy in the apertures: but pipes will diſcharge much more water in the ſame time, than a thin hole of the ſame diameter, as may be ſeen by the following experiments, viz.

	Cubic inches.
A pipe of 4 inches long diſcharged per minute . .	12,279
———— 2 inches in length	12,188
———— 1½ inches long diſcharged	12,168

The water being kept to the ſame perpendicular height; ſo that we ſee the longeſt pipe diſcharged the moſt water; but where the aperture was the ſame, only a thin hole, the diſcharge was no more than in a proportion of 10 to 16, or about 7,674 cubic inches in a minute. This ſeems a little extraordinary, and is attempted to be accounted for in this way:—The eaſy mobility of water makes it preſs towards an aperture, where it is the leaſt reſiſted, in a radiant form; as in the reſervoir *a b*, fig. 7, Plate XXI. where the arrows point the direction of the fluid towards the aperture: now as the particles advance in oppoſite directions near the bottom, they form, by their colliſion, a little whirlpool at the place of their meeting, and paſs through the hole in a circular thread, conſiderably ſmaller than the hole itſelf, as appears at *c*; by this means an aperture in a thin plate will not diſcharge ſo much water in a given time (and of the ſame height), by nearly one third, as a pipe of two or three inches long, bored with the ſame inſtrument, and exactly of the ſame diameter: for the pipe prevents the eddy, and, therefore, receives the perpendicular weight leſs obſtructed. The effect is much the ſame in lateral pipes as in perpendicular ones, when the head of water is the ſame, as *d*, fig. 7, Plate XXI.

From theſe premiſes we learn, that the quantities of water diſcharged through different apertures, at different heights, are as the ſquare of the diameter of the pipes, to the ſquare roots of the perpendicular heights of the water above the pipes. This rule ariſes from the known qualities of the circle, that its area is as the ſquare of its diameter, viz. a circle twice the diameter of another contains four times the ſpace; and one three times the diameter of another, nine times the ſpace, &c. So it is with the conducting pipes; one twice the diameter of another will diſcharge four times the water, when the head is the ſame height, &c. It has alſo been ſhewn that a pipe of equal bore with another, but four times as low beneath the ſurface, will diſcharge twice the quantity of water in the ſame time; if nine times lower, three times the quantity; therefore, their diſcharge is as the ſquare root of their depth.

Example. If a hole of one inch diameter, 4 feet beneath the ſurface, will in 1 minute diſcharge about 5,798 cubical inches of water; what quantity ſhould be diſcharged by a pipe of 2 inches bore beneath a head of 9 feet?

As 1, the ſquare of 1, multiplied by the ſquare root of 4, viz. 2,

Is to 4, the ſquare of 2 (the diameter of the lower pipe), multiplied by the ſquare root of 9, viz. 3, = 12,

So is 5,798, the cubic inches of water,

To 34,788 cubic inches, that will be diſcharged by a pipe of 2 inches diameter, kept 9 feet below the ſurface one minute.

Or as 2 : 12 : : 5,798 : 34,788, &c.

If a pipe of two inches bore fill a ciſtern in an hour and an half; what bore ſhould a pipe be that would fill it in half the time?

As leſs requires more in this queſtion, it muſt be worked in reciprocal proportion.

As 90 minutes, the time in which it is now filled,
Is to 4 (the ſquare of 2 inches),
So is 45 minutes (or half the time)
To 8, the ſquare of the diameter of the pipe ſought, and whoſe ſquare root is 2.828, the diameter of the pipe required.

On the Syphon.—This is nothing more than a bent tube; and its uſe is that of decanting fluids out of wells, ciſterns, barrels, &c. If the tube *a b*, fig. 1, Plate XXII. be filled with water, and then (with a finger on *a* and *b*) it be inverted, and its ſhorter leg immerſed in *c*, full of water, the whole will riſe over the vertex *d*, and be diſcharged at *b*. When the ſyphon is thus immerſed in water, its outer leg is conſidered as from *d* to *b*; but its inner leg is only conſidered as from *d* to the ſurface of the water at *e*; for the water below *e* is balanced by the water on the outſide of that leg; ſo that the weight of water in the leg *d b* is ſo much heavier than that in the leg *d e*, that it will fall by its own gravity, and would leave a vacuum at *d*, if the preſſure of the atmoſphere on the ſurface *e* did not prevent it. Hence it is to the preſſure or weight of the atmoſphere that we are indebted for the action and uſe of the ſyphon.

This is eaſily proved by a ſyphon whoſe legs are of an unequal length, as ſuppoſe the inner leg to be *a d*, and the outer leg only *d g*; in this caſe, the ſyphon will run till the water becomes level with the end *g*, and there ceaſe; the water hanging in the leg *d g* (a balance for that in *d c*), until a bubble of air gets in at *g*, then that leg becomes lighter, and the water returns into the veſſel.

2d. The ſyphon fountain, fig. 2, Plate XXII. alſo demonſtrates the preſſure of the air to be the cauſe why water ſeems to riſe above its level in the ſyphon, but which is not ſo in reality; for water cannot be raiſed above its level by this inſtrument. In fig. 2, *a* is the outer leg of the ſyphon, which paſſes through, and is fixed in, the braſs cap of the glaſs cylinder *c*. The inner leg *b* alſo paſſes through the cap, and terminates above it in a capillary ſpouting pipe. If the cylinder be placed upright on the ground, a few ſpoonfuls of water may be poured into it at *d*; which will drive out an equal quantity of air through the leg *b*. If then the whole be inverted as in the figure, and the leg *b* immerſed in water, the water in the cylinder will fall through the leg *a*, and driving the air before it, leave the air rarefied in the cylinder. The preſſure of the air on the water in the cup *e* will then force the water into the cylinder in a beautiful jet.

3d. Tantalus's cup, fig. 3, Plate XXII. is another device to ſhew the action of the ſyphon. This cup is open at the bottom *c*, ſo that the longer leg of a ſyphon may be cemented into it, and make the cup capable of holding water; if water be then poured into it nearly to the bend of the ſyphon, the water will remain in it, as in a common cup; but if an apple be dropt into the water, it will begin to run out at the bottom, by the apple forcing the water over the bend of the ſyphon.

4th. In limeſtone mountains, caverns are very common; and in their entrance large irregular rocks are generally jumbled together, ſo that it is not unnatural to ſuppoſe ſyphons may be formed amongſt them, through which the water in the caverns muſt iſſue; wells formed from water, thus iſſuing, will ebb and flow, ſomething like the ſea, but by no means with the ſame regularity. As clouds are attracted by mountains, and alſo driven againſt their tops and ſides by wind, mountainous countries are generally wet countries. But it cannot be ſuppoſed that *all* the water, thus falling on mountains, runs down their ſides; by far the greateſt part ſinks into the chinks and pores of the ground and rocks, running in promiſcuous channels, or percolating, through the gravel, till it finds a convenient place to break out; there it commences a ſpring, or a fountain, perhaps the head of a large river. For, dead and inanimate as our mother Earth appears, we find her thus fraught with veins and arteries like the animal body, and we muſt actually prick one of thoſe veins, before we can get water to ſupply a common pump. It is, therefore, the rain falling on the higher grounds, by which the lower are ſupplied with wells and ſprings. Rain falling on the mountain, fig. 4, Plate XXII. and percolating through the fiſſures *a a*, will drop into the cavern A, and in time fill it up to the level *b c*, when it will fall over the bend of the natural ſyphon *d c n*, and the whole be diſcharged at *n*: the fountain *n* will then remain dry till the cavern is again filled up to the level *b c*, &c. and hence ebb and flow.

5th. The diſtiller's crane, or ſyphon, fig. 5, Plate XXII. begins its action by the *vis inertiæ* of the fluid into which it is immerſed. Let B be a barrel, and *n* its bung-hole. The ſyphon from *n* to *r* is about three feet long, and about one inch diameter; it has a ſtop-cock near its end, which muſt be ſhut, before the ſhort end is put through the bung-hole. If the barrel be full, one would not think the liquor would riſe of itſelf over the bend *m*; but the cock being ſhut, the air in the crane will be condenſed by the endeavour which the liquor within it will have to riſe to its level: if then the cock be ſuddenly opened, the liquor will inſtantly ſpring over the bend *m*, and become decanted.

On this principle, many years ago, I invented an uſeful, cheap, and ſimple machine to raiſe water above its level by its *vis inertiæ*, and the flexibility with which the particles of water ſlide over one another, for the purpoſe of making a ſhip pump herſelf. The firſt idea was that of a ſquare cloſe box, to be placed in the middle of the ſhip, reaching from her bottom, a little above the level of the water in the ſea. In this box were triangular partitions, as fig. 6, Plate XXII. *a b* is the inſide bottom of the ſhip; *c* is an opening into the firſt partition of the box; *d d d* are valves in each partition, opening upward. When the ſhip heels to the right, the bilge water ruſhes in at *c*, and opens the valve *d*; when the ſhip heels to the left, the valve *d* is ſhut, and the water (following the motion of the ſhip) ruſhes through the valve *e*, and ſo to the top through the different partitions.

The objections to this mode of raiſing water, by the motion of the ſhip, were, that it occupied too much room in an important part of her; and the loweſt valve would be liable to be choaked up by ſand, coals, and other dirt: I alſo found, that though in a model the momentum of the water was quite ſufficient to open the valves, yet that much of that momentum was loſt, by the ſhort range the water had from one ſide of the box to the other. Why not, therefore, make that range the whole length of the ſhip, and leave the water unconfined? Suppoſe, in fig. 7, Plate XXII. *a b* the length of the ſhip's keel, and that by placing it on the fulcrum *c*, that keel can be made to imitate the rolling, or pitching of a ſhip. This model is an open box between *d* and *e*; but ſhut on the ſides *e g* and *g b*. On *g b* is fixed a ſloping pipe (conforming to the ſhape of the ſhip), having the valve *i* opening into it. The other end of the model being the ſame, needs no further deſcription. The model being now held level on the fulcrum *c*, and nearly filled with water, if the end *b* is depreſſed, as in the figure, the water will ruſh into the box *e g b*, and puſhing open the valve *i*, riſe conſiderably high in the tube *i*. The valve will be inſtantly ſhut by the water now on its top, and on the end *a* being depreſſed, the water will ruſh into the oppoſite box, puſh open the valve *n*, and riſe in the pipe *n*. This operation continued, the water will riſe higher and higher in the pipes, till it is thrown out of the ends *o* and *p*, every returning motion of the ſhip. Why this ſhould not anſwer at large, as well as in model, I know not. It has been ſhewn, explained, admired, and forgot.

The model to repreſent the hold of the ſhip was about three feet long, four inches wide, and four inches deep, as ſhaped fig. 7, Plate XXII.: ſixteen gills of water were put into it; and then it had a motion given it on its fulcrum *c*, ſo as to form an angle with the horizon of 20°, and each pitch took up one ſecond of time. In every two pitches (after the pipes *o* and *p* were full), it diſcharged one ſixteenth of the bilge water at twice the height of its depth.

Another model for the ſame purpoſe, was two force-pumps, actuated by a globe of lead, as fig. 8, Plate XXII.: this machine was to be placed on the bottom of the ſhip, and worked by her motion. The pipes *o n* communicated with the bilge water, ſo that when the ſtern of the ſhip ſunk beneath the horizontal level, as in the figure, the ball rolled down the lever L to *a*, and by its weight preſſed down the piſton *c*; forcing the water under it into the cloſe box *d*. By the ſame motion the piſton *s* was raiſed, and making a vacuum in the ſpace *u*, the bilge water was preſſed into it, through the valve *v*. Upon the ſtern of the veſſel being depreſſed, the ball would roll down the channel L, and ſtop at *e*, by which the piſton *s* would be forced down, and the water under it forced into the box *d*. When this box became full, the water would preſs open the valve *q*, and riſe up the pipe *b* to the deck of the veſſel.

I alſo ſpent ſome time and money in contriving and conſtructing a pendulum pump, to be actuated by the motion of a ſhip; but they all required more room than could be ſpared for them. If thoſe hints, however, can ſtimulate to, or aſſiſt in, the proſecution of ſo deſirable an addition to the perfections of a ſhip, I ſhall think theſe attempts not wholly loſt to mankind.

Conducting Pipes.—Water, like all other fluids, flows the eaſieſt through, or over, itſelf: hence horizontal pipes of conduct ſhould be larger than can be filled by the water that runs through them; ſo ſhould ditches and drains; for the ſides of pipes, and drains, that are filled with water, retard it by great friction. If horizontal pipes are filled from a reſervoir, they diſcharge leſs in proportion to the diſtance they convey water; and that nearly in an inverſe ratio to the ſquare roots of that diſtance; i. e. if a pipe, 4 yards long, diſcharge 20 gallons in a minute, the ſame width of pipe, 9 yards long, would diſcharge 13.3 gallons: for as 2 (ſquare root of 4) is to 20 gallons, ſo is 3 (ſquare root of 9) to 13.3.

It is a curious fact, that if the hole *c*, and the pipe *e*, fig. 7, Plate XXI. be bored with the ſame tool, the pipe will diſcharge nearly one third more water than the hole in the ſame time. (See Hydroſtatics.)

Air will ſometimes, in crooked tubes, form lodgments, that will ſtop flowing water, if its fall be inconſiderable. If I pour water into the funnel *a*, fig. 9, Plate XXII. the water will proceed to *b*, and there trickle down the part *b c*, leaving that ſpace nearly filled with air, which will be impriſoned by water that will fill up the bottom at *c*. If more water be poured in at *a*, the column of air *b c* will force up the water to *d*, which alſo trickling down the declivity *d e*, will lodge between *e* and *n*, and prevent any water from making its way out at *o*. In pipes of conſequence, ſometimes a ſtop-cock is fixed at *b* and *d*, to let out the lodgments of air.

Of Pumps.—In the common ſucking-pump, as it is called, water riſes by the preſſure of the atmoſphere on the ſurface of the well. The principle may be more particularly ſeen by the glaſs model, fig. 10, Plate XXII. where *a* repreſents a ring of wood, or braſs, with pliable leather faſtened round it, to fit the cylinder A. Over the hole, in this ring, is a trap-door, or valve of metal, covered with leather, part of which often ſerves as a hinge for the valve to open and ſhut by. The handle and rod *r* end in a fork *s*, which, paſſing through the ring, or piſton, is ſcrewed faſt to it on the underſide. Below this, and generally over a tube of a ſmaller bore, as *z*, is another valve, *v*, opening upward, which will ſuffer water to paſs up, but not down. Now, when the piſton *a* is pulled up by the handle (its valve being cloſe), the column of air on its top is lifted, and a vacuum underneath takes place; to ſupply this, the air, in the lower part of the pump, preſſes into the vacuum, and hence the whole column of air *within* the pump becomes lighter than a ſimilar column *without* the pump. By the ſuperior preſſure on the well, the water is forced into the pump, and through the valve *v*, which ſhutting, prevents its return. The piſton being now forced down (as in the common act of pumping) through the water (which opens the piſton valve), the next ſtroke lifts the water to the ſpout of the pump, and making a vacuum underneath, at the ſame time a freſh quantity is forced through the lower valve, which, if very tight, will keep the water there; ſo that the pump, remaining always full, water is delivered at its ſpout, on the firſt motion of the handle. As this effect is produced by the preſſure of the atmoſphere, and as it is found that a column of water, of about thirty-two or thirty-three feet high, is equal in weight to a column of air of the ſame baſe of forty-five miles high, therefore, the piſton *a* muſt always work below thirty-two feet from the ſurface of the water; perhaps if it never works more than twenty-eight feet above the water, it may be better, as the air varies much in its weight at different times.

Many attempts have been made to reduce the friction and wearing of this pump: to reduce the friction of a pump, is all that art can do; for the column of water muſt be lifted by an adequate power, let the contrivance of the pump be what it may: metallic conical valves are great improvements. They are uſefully formed as fig. 11, Plate XXII. which is a ſection of the whole piſton: *o* is the conical valve, ground very even and ſmooth to fit its cavity in the piſton *a a*; it is kept in its cavity by the weight *g*, and directed into it by the wire acting through *n*, when lifted up by the water. The piſton is leathered as uſual, and the iron crane *s* goes through it, and is faſtened by the ſcrew nuts *r r*. *c* is the pump rod. Both the upper and lower valves are made in this form; if well made, they are water-tight, and never wear.

The manner in which this valve is applied, may be ſeen in the ſection of the pump, fig. 12, Plate XXII.

To leſſen the friction of a piſton, and prevent the injury it often ſuffers from gravel, ſand, and other hard ſubſtances, a ſquare trunk is uſed for the body of the pump, as fig. 13, Plate XXII. and a pyramidal piſton, as fig. 15. This pump, for temporary drainage, and to be worked by one man, is about four inches ſquare within, and ten or twelve feet long, having a valve *d* opening into the trunk. The piſton is generally made of ſtrong horſe-leather, firſt cut out into goars, as fig. 14, Plate XXII. and when ſcrewed together, appears as *c*, fig. 15, Plate XXII. The vertex of the pyramid is nailed to the end of the handle *c*; and the ſides of the pyramid are ſuſtained by ſmall chains, or cords, faſtened to the ſaid handle: this precaution prevents the ſides from rolling down, or giving way, when long ſoaked in water. This pump lies ſloping on the bank of the pond, or pit, it is intended to drain; requires no faſtening; and is eaſily removed: its piſton, when thruſt into water, gives way at its ſides, and anſwers the purpoſe of a valve, letting water paſs through it with the utmoſt eaſe; but on its being pulled up, the ſides ſpread cloſe to the ſides of the trunk, driving up all the water before it, without more friction than is neceſſary to prevent the return of the water. This cheap and ſimple machine is peculiarly adapted for draining caiſſons, ponds, marle pits, quarries, &c.

To irrigate land in dry weather, without fatiguing the labourer, is of great importance in agriculture. A portable machine, of the ſhape of fig. 1, Plate XXIII. will, I believe, anſwer this purpoſe very well. In moſt fields there are ditches or ponds, on the banks of which (as on a fulcrum) this bucket-lever will turn. *a b* are two inch boards, ten or twelve feet long, ten or twelve inches wide, and kept aſunder by ſides, water-tight, of two inches. On the upper board is fixed a ſtaircaſe of battens, fixed acroſs, as *o o*. Down this ſtaircaſe a man walks to *b*, when his weight will ſink the bucket *c* into the water, which will riſe through the valve *d*. If he then walks up towards *a*, the bucket *e* will riſe, by which its water will run under his feet and between the boards *a* and *b*, and be diſcharged at the hole *g* into a trough or channel, which will convey it away into the field.

Another method by which I have watered land was by means of a portable boat or punt; in the bottom of which was fixed an upright pump, communicating with the water in the pond, but preventing its entrance into the boat. This pump had a diſhed top, as *c c*, fig. 2, Plate XXIII. ſtuck full of nails without heads; on this a wooden fruſtum, or a portion of a globe, was placed, having the maſt *d* fixed in it; and under it (by a chain) the piſton of the pump, made weighty enough to keep the maſt upright when there was little wind. The ſail on this maſt kept always on the lee ſide of the maſt, from what quarter ſoever the wind blew, which, nodding to the ſucceſſive impulſes of the wind, worked the pump, and forced the water over the bank of the ditch in the ſpout *g*. This little boat being moored by the ſtones *h* and *i* by way of anchors, kept the pump going whenever there was a wind, and watered its neighbourhood without trouble or attention.

Archimedes's ſcrew-pump, fig. 6, Plate XXIII. though one of the oldeſt methods of raiſing water, is not one of the worſt, particularly for temporary drainage. Water riſes in this hollow ſcrew by endeavouring to fall. Its lower end being in the water, its upper may be raiſed ſo high, that the parts of the thread *c d* may lie nearly horizontally; yet not ſo much ſo, but that the declivity between *d* and *c* ſhall ſuffer the water to fall, and form lodgments in the lower parts of the thread, as *c c c*. This engine generally conſiſts of three or four threads encloſed within a cylinder.

The Rope-pump. Fig. 1, Plate XXIV.—This ſingular pump conſiſts of two or three hair ropes paſſing over a three-groved pulley in the box *z*, projecting over the well: they alſo paſs under a pulley in the water, and are kept tight by a weight *e*. The upper pulley is put into ſwift motion by the wheel A. To the aſcending parts of the ropes a quantity of water adheres, and is diſcharged with great violence in the box *z*. This adheſion is occaſioned by the preſſure of the atmoſphere towards the ropes; as a conſiderable rarefaction of the air is made near the ropes by the ſwiftneſs of their motion. A man will raiſe about eight or nine gallons per minute out of a well near 100 feet deep with this pump.

The Forcing-pump.—The principle of this pump may be ſeen in the model, fig. 2, Plate XXIV. where *a* repreſents a ſolid piſton, which, when drawn up, rarefies the air below it, and, of courſe, preſſing lighter on the water within the pump than the preſſure is on the well, that greater preſſure forces up the water through the valve *c*, which (being made a little ſpecifically heavier than the water) ſhuts, and prevents the return of the water. The piſton *a* being now preſſed down, the water above *c* is forced through the valve *d* into the air-veſſel *g*. This veſſel has a pipe *e* ſcrewed tight into its top, that reaches nearly to the bottom of the air-veſſel *g*, and is open at both ends: when the water, therefore, covers the lower end of this pipe, the air above it becomes a priſoner, and condenſed, as the water is forcing in, which, by its reaction on the ſurface of the water, forces that water through the pipe *e* with great velocity, and in a continued jet. It is on this principle that the extinguiſhing engine is formed, however different its conſtruction may be; which is ſometimes with two forcing-pumps and an air-veſſel between them: for the air-veſſel is not only uſeful in preventing the burſting of the pipes, but in adding ſo conſiderably to the velocity of the water, that a raging fire is rather daſhed out than extinguiſhed by it; for ſo great is the repulſive force of fire, that water barely poured on dry combuſtibles would make them burn with greater fury, the water being carried off by the fire in the character of ſteam as faſt as it is poured upon it. See No. 1, in the Table of Specific Gravities, fig. 3, Plate XXIV.

To make the piſton of a ſucking and forcing pump to act both upwards and downwards, and thereby produce a continued ſtream of water without the pulſations common to pumps, ſee fig. 6, Plate XXIV. This piſton is ſolid, and, when drawn up, rarefies the air within the pipe *c*, up which the water will flow, and through the valve *d*: on the deſcent of the piſton, that water will be forced into the air-veſſel *e*; and a vacuum will be made above the piſton, which, communicating with the pipe *g*, will rarefy the air ſo much within that pipe, that the water will flow up it into *c*, and cover the piſton. This water alſo will be forced up into the air-veſſel by the aſcent, or next ſtroke, of the piſton; ſo that water is raiſed both by the aſcent and deſcent of the piſton.

For the moſt approved engine for extinguiſhing fire, ſee fig. 1, Plate XXVI. as a ſection of it. *a* is a ſemicylinder of caſt-iron, having a piſton *c*, moved by the arms *b b*. This piſton, or ſlider, is water-tight on all ſides, as well as in the ſocket *g*. When the handle *b* is raiſed, the piſton will be raiſed into the poſition *c*, and leave a vacuum in *a*: the water out of the trunk A will then riſe up the pipe *n*, through the valve *o*, and flowing through the hole *z*, will fill the ſpace *a*. On the next return of the handles *b b*, that water will be forced through the valve *s* into the conducting-pipe, of which *u* is a ſection, and alſo into the air-veſſel B, while a vacuum is made on the ſide of the piſton *c*, and the ſame effect will take place on that ſide as on that of *a*; viz. the valve *r* will open, and the ſpaces *c r* will become filled with water, which, at the next ſtroke, will be forced through *v* into the conducting-pipe *u*, and the air-veſſel B; a vacuum being thus formed both before and behind the piſton *c*, the water of courſe follows on both ſides, and hence the ſemicylinder full of water is forced into the conducting-pipe on every return of the handles *b b*. Twenty men may be employed to give this alternate motion to the machine, as may be ſeen in the elevation of it, fig. 2, Plate XXVI. where two pipes may be employed, as C and D, and ten men to each of the handles *w x*. Dirt and gravel very frequently render other engines uſeleſs at the moment when they are moſt wanted: this is never ſo obſtructed; for if any gets into the ſpace *a c*, the firſt return of the piſton *c* will throw them out through the openings *z y*; and ſhould any dirt form a lodgment about the valves *o* or *r*, the ſcrews *q q* can inſtantly give acceſs to the inſide.

Fig. 3, Plate XXIII. is a boat that can move againſt the ſtream or tide of a river; *a a a* are two ſets of paddles, or oars, on one axle, *c*. Theſe project before the ſtem of the boat, as in the plan, fig. 4, Plate XXIII. On the axis there is a conical part *x*, on which a cord or rope is coiled three times round: the end of this cord is faſtened to a ſtake by a projecting ſide of the river, and, as it uncoils, hangs over the ſtern of the boat, as *m m m*. The conical part of the axle *x* obliges the cord to ſlide down it, ſo that the cord never coils round any other part of the axle. Three or four boats may move or follow one another on the cord *m*. There ſhould be two cords of about 100 yards each, capable of being eaſily attached to, and detached from, each other; ſo that one might be carried forward up the river, and its end faſtened, while the other was in uſe. This experiment was tried, and ſucceeded, on the Thames.

Another method, as fig. 5, Plate XXIII. is to make a boat *walk* againſt the ſtream. The axle *c*, fig. 4, is a crank, as *z*, fig. 5; on this crank are looped the poles *q q*, with iron terminations to make them ſink, and prevent their wearing. Theſe poles walk under the boat, on the bottom of the river; and muſt be rather longer than the boat, to be applicable to the various depths of the river. This boat being long in proportion to its width, becomes a rudder, and always turns its head againſt the ſtrongeſt and moſt rapid part of the ſtream; and, therefore, guides itſelf.

Fig. 7, Plate XXIII. is a boat machine for clearing the bottoms of rivers of gravel, mud, &c. It is moored over the bottom to be cleared, and is worked by the current of the river, by paddles on both ſides of the boat, fixed at the ends of an axle, as in fig. 4, Plate XXIII. On this axle is the pinion *a*, working into the teeth of the wheel *b*: this wheel is ſupported on the fixed frame *g*, which is the ſide of a ſquare hole that goes through the bottom of the boat, made tight to prevent water from getting into the habitable part of the boat. *c g x* is a frame of boards made to ſlide up and down through the hole in the bottom of the boat: in the bottom of this frame runs the roller *m*; over which, and the toothed roller *b*, goes the leathern band *s s s*, having buckets *e e e* fixt in it at proper diſtances. This band is made to lengthen or ſhorten, as the river deepens, or grows ſhallow; and the weight of the frame *c g x* preſſes the buckets againſt the gravel, ſo that they may ſcrape it up, and riſe full. When a bucket riſes over the roller *b*, its mouth becomes inverted, and the gravel is thrown down into the body of the boat.

Boulton and Watts's Steam-engine, Plate XXVII.

A. The boiler, about half filled with water.

B. The ſteam-pipe, that conveys the ſteam into the cylinder.

C. The door, where a perſon may enter to clean out the boiler.

D. The loaded, or ſafety valve; forced open by the ſteam when too ſtrong; or to be opened by the handle *c*.

E. Feeding-pipe, from the warm-water ciſtern S.

F. Fire-door, opening to the fire under the boiler.

G. The aſh-hole.

H. The cylinder, having a piſton in it, on the end of the rod *d*, which works through the air-tight ſtuffing-box *o*.

I. Nozzles, where the ſteam is let out.

K. Plug-frame, to open and ſhut the valves in its riſing and falling; thereby ſuffering the ſteam to paſs to the condenſing pump Q.

L. Beams that ſupport the cylinder.

M. The exhauſtion-pipe, that conveys the ſteam through the cold-water well O to the pump Q.

N. Injection-pipe, in the cold well, to throw in a little cold water into the exhauſtion-pipe M.

O. The blowing-pipe, to let out air that might accumulate in the air-pump Q.

P. The barometer, to compare the ſtrength of the ſteam with the preſſure of the atmoſphere.

Q. The air-pump, immerſed in a well of cold water. When its piſton aſcends, by the chain Q, it draws the ſteam out of the cylinder, and condenſes it by the coldneſs and the vacuum in the pump. The ſteam becoming water by this means, the piſton deſcends into it, the piſton-valve is opened by the water (as in a common pump), and the next aſcent of the piſton forces that warm water through the box R up the pipe *r* into the ciſtern S (which pipe is cut ſhort in the drawing, but it begins at the box R). This water ſupplies the boiler.

R. The box of the pipe *r*.

S. The ciſtern of ditto.

T. A forcing-pump, whoſe ſolid piſton is forced down by the weights *s*, and the piſton of the cylinder H drawn up. When the ſteam from the boiler forces down the piſton of H, the piſton in T riſes, and rarefying the air in the inſide or barrel of the pump, the preſſure of the atmoſphere on the ſurface of the well forces up the water as in a common pump: but by the deſcent of the piſton in T, the water is forced through the pipe *x* to the place where it is wanted.

W. Is an air-veſſel to prevent the burſting of the pipes.

Z. The pipe to feed the condenſer-ciſtern O N Q.

Y. The great lever-beam.

This excellent machine is ſometimes made to work by the preſſure of ſteam both upward and downward; i. e. the ſteam can be made to preſs the piſton up, as well as down. This adds conſiderably to the firſt expence, and the continued expence of fire.

Steam-Engine, with the Cylinder in the Boiler.—It is ſo important an object to keep the cylinder hot, that in the laſt engine the condenſation of the ſteam is performed in a ſeparate veſſel, at a diſtance from the cylinder. To do this more effectually, I have had ſeveral engines made with the cylinder within the boiler, as Plate XXVIII.

A. The boiler, with the bottom part of the chimney paſſing through it.

B. The cylinder within the boiler, and fixed to its top; having holes all round that top to let in the ſteam.

C. Piſton, the rod of which works through a collar of leathers (or ſtuffing-box) and is ſuſpended from the great lever T. A joint in this rod, ſliding in a groove, makes the ſtroke perpendicular.

D. A pipe from the cylinder B, communicating with the injection-valve, and the cold water injection-pipe I I, leading from the cold water ciſtern O.

E. Steam-valve.

F. Injection-ditto.

G. G. Eduction, or exhauſting-pipe, from the cylinder to the hot-well S.

H. Snifting-clack, to let out air from the cylinder.

J. Pump for feeding the boiler.

K. Hot-ciſtern.

L. Feed-pipe, to ſupply the boiler with warm water from the hot-well K.

M. Waſte-pipe, to convey away the water when the hot-ciſtern is too full.

N. The ſucking and forcing pump, to raiſe water from a well, or river, to the ciſtern O.

O. Large ciſtern, reſervoir, or penſtock, from whence water can be turned on wheels, or made to ſupply towns, houſes, &c.

P. Connecting rod from the beam T to the crank, which gives motion to the great fly.

Q. Q. Q. Plug-tree, for working the geer, i. e. to open and ſhut the valves, and work the hot-pump.

R. Safety-valve, to prevent the burſting of the boiler; if the ſteam be too ſtrong, the valve opens and lets it out.

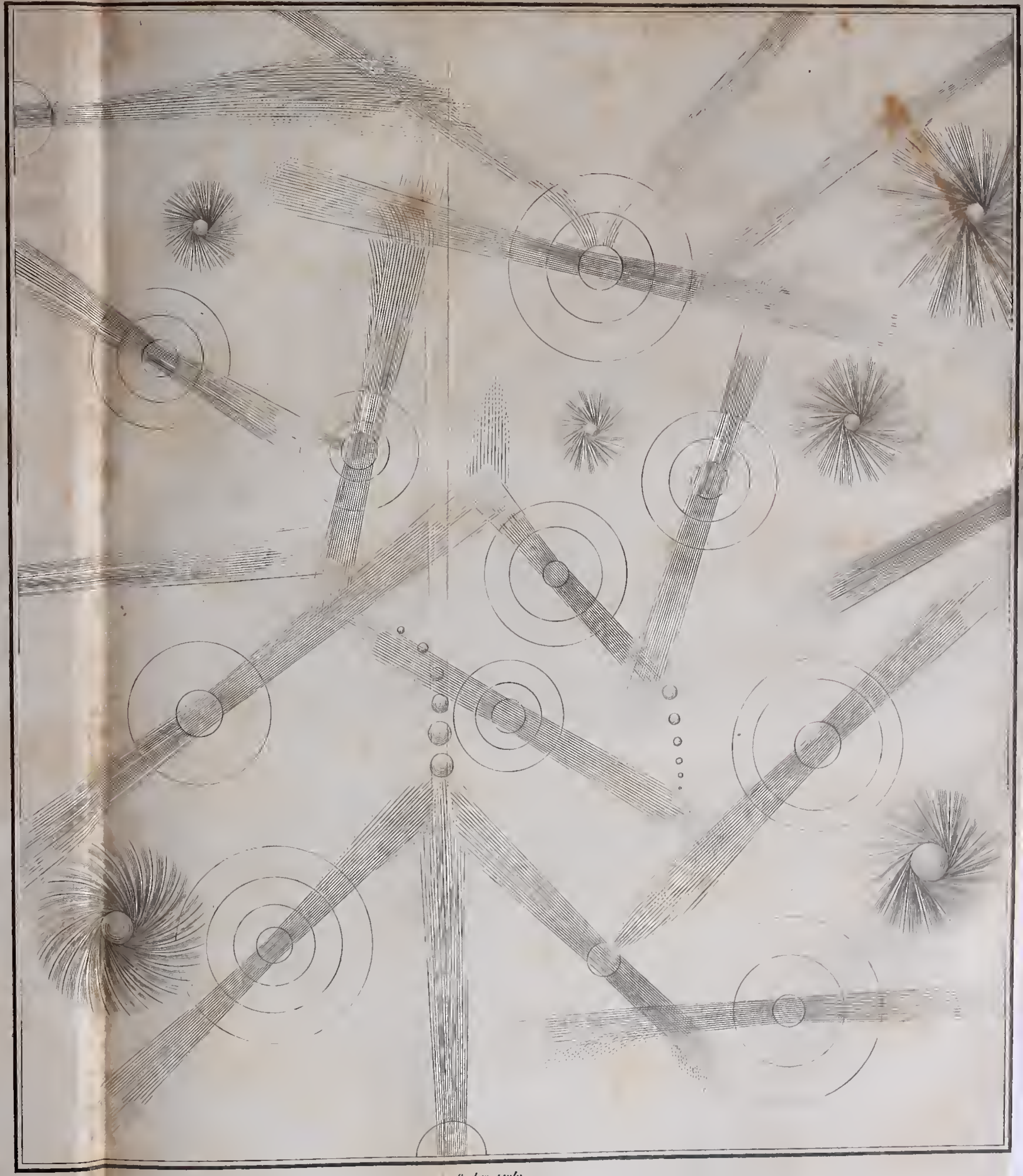
S. Hot-water well.

T. The great beam, or lever, connected with the piſton C, the plug-tree, and the pumps.

Theſe kind of machines approach nearer to the animation and powers of animal mechaniſm, than any yet invented by man.

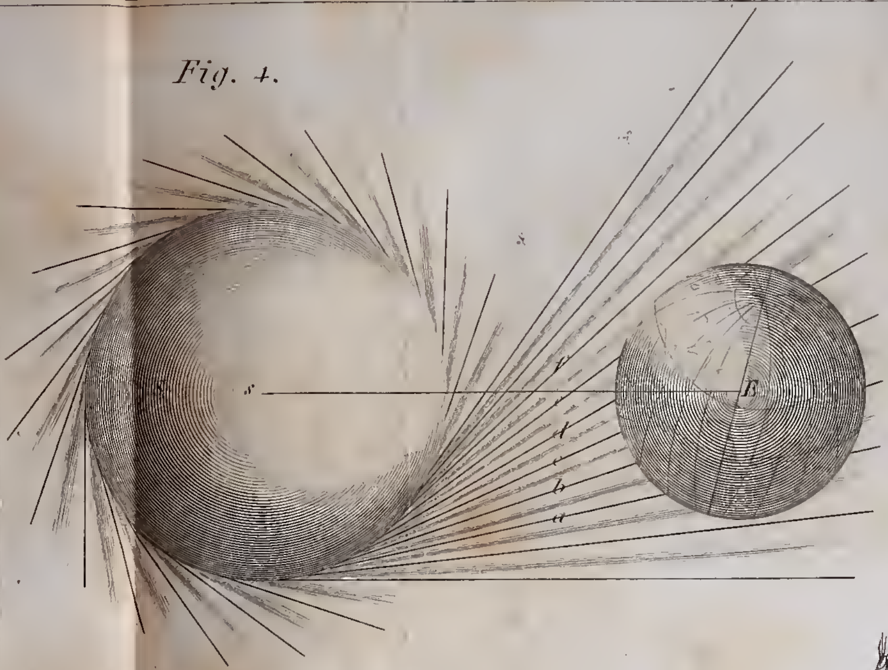
END OF THE FIRST VOLUME.

[*T. Daviſon, White Friars.*]



Barlow sculp.

Fig. 4.



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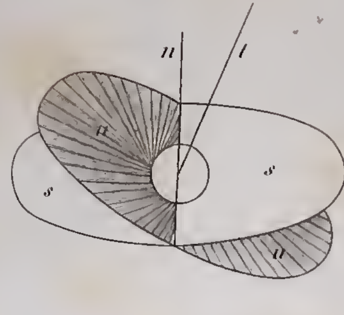

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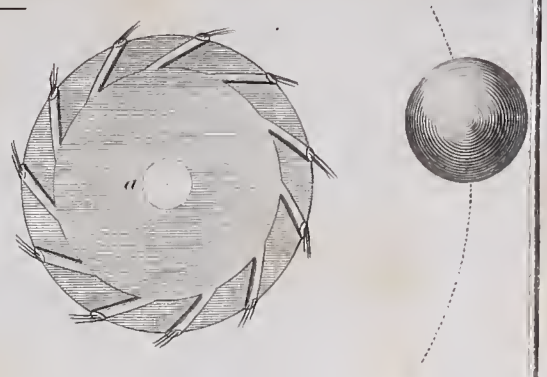

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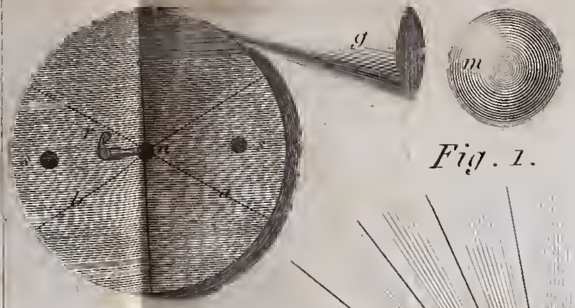

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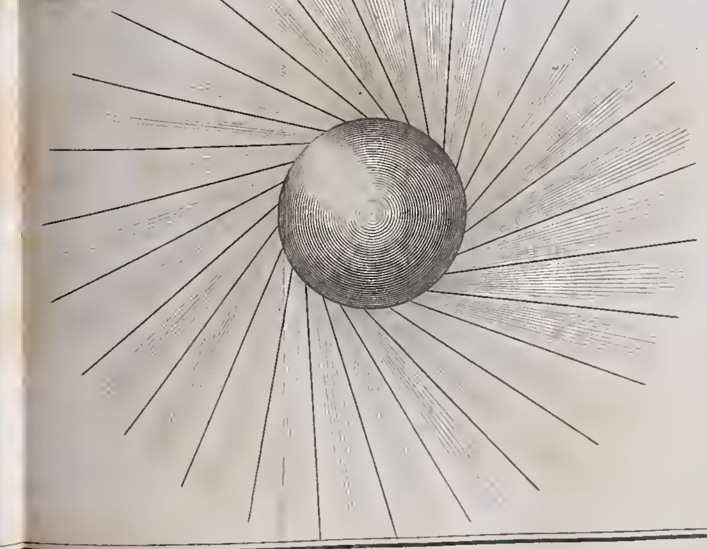

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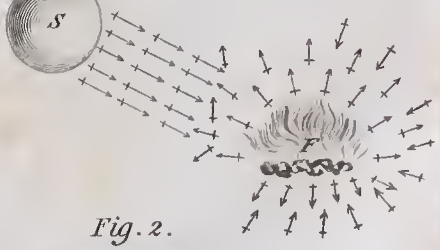

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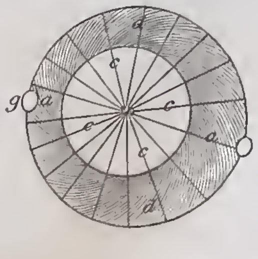
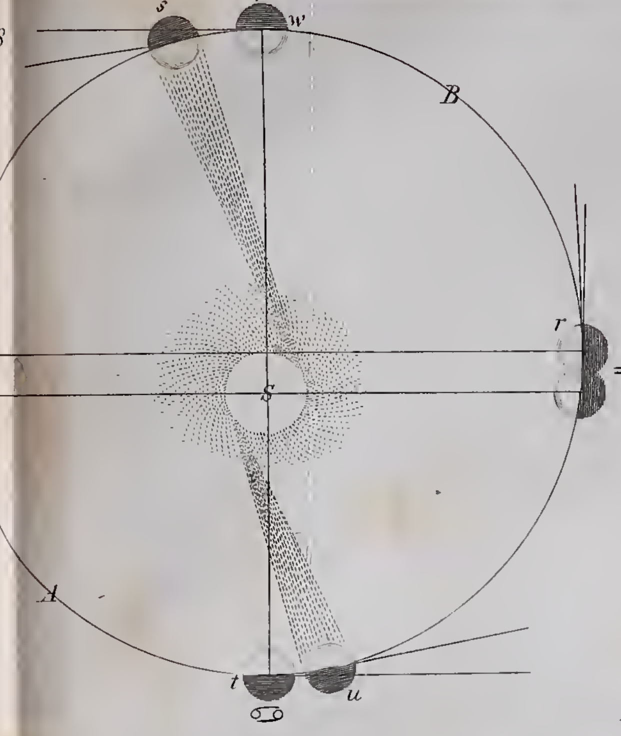


Barlow sculp.

ON LIGHT.

Pl. III.

Fig 8



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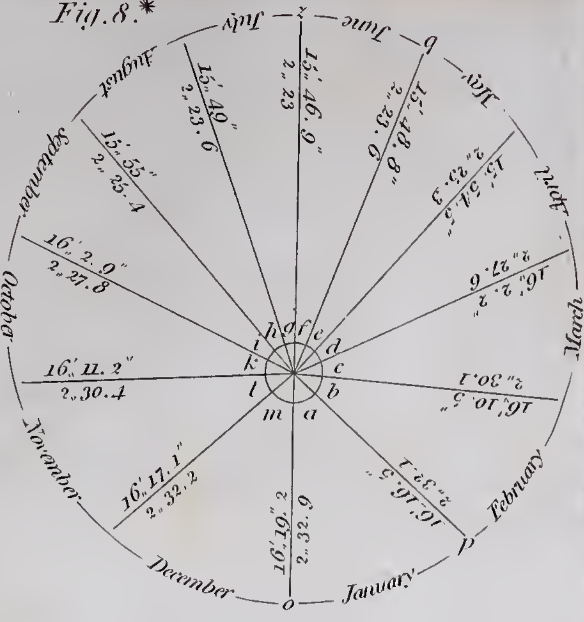

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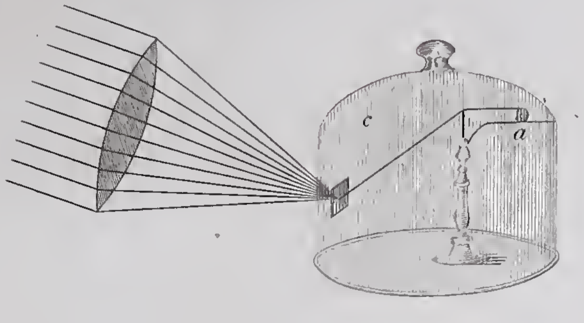

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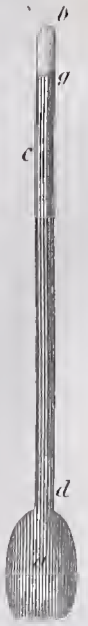
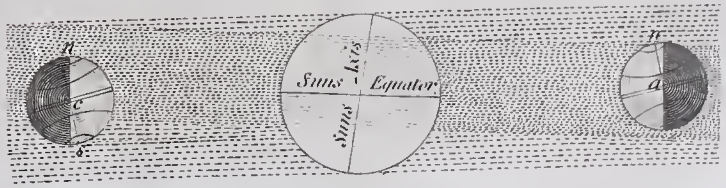


Fig. 13.

Fig. 12.



Barlow Sculpt.

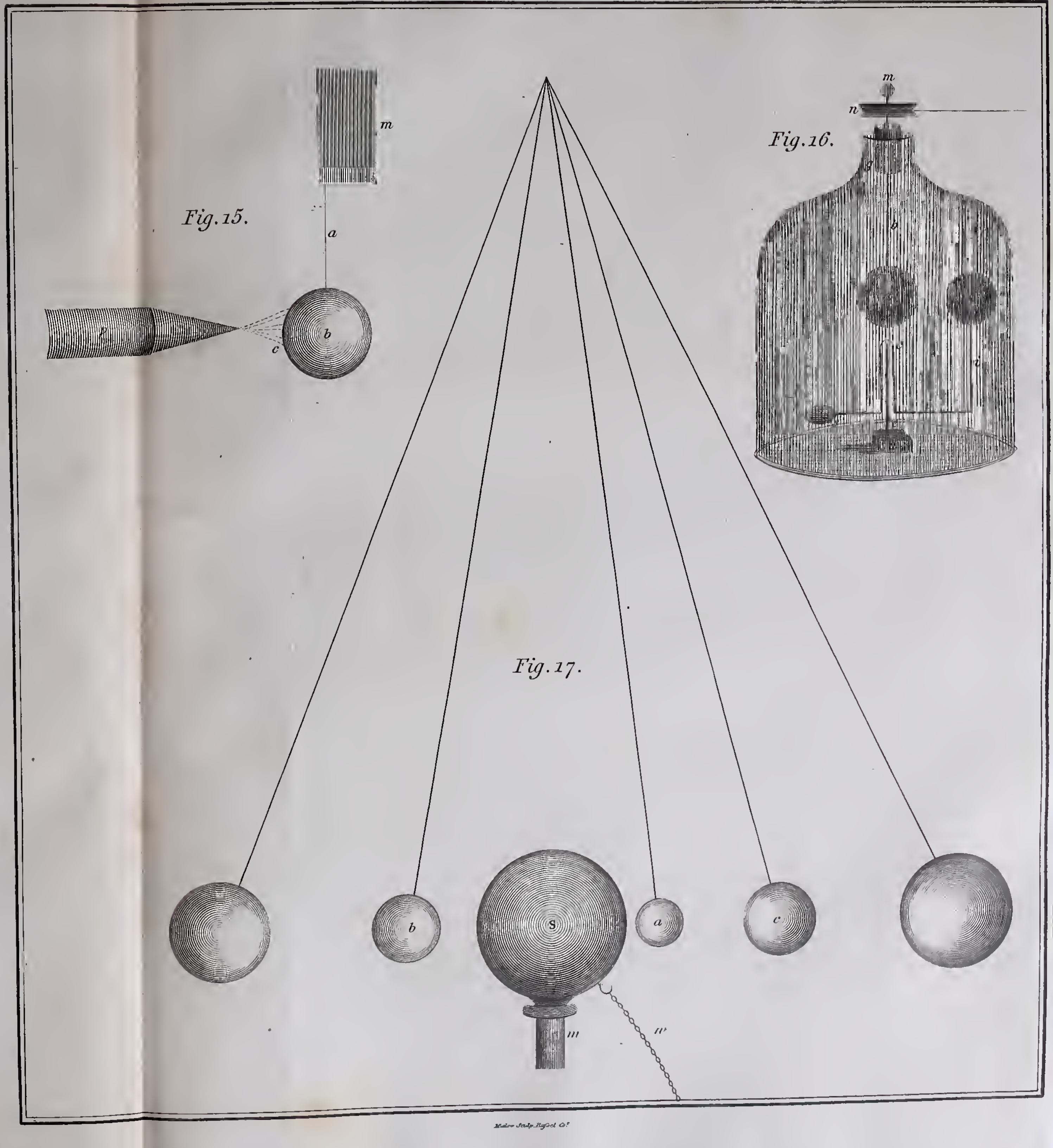


Fig. 15.

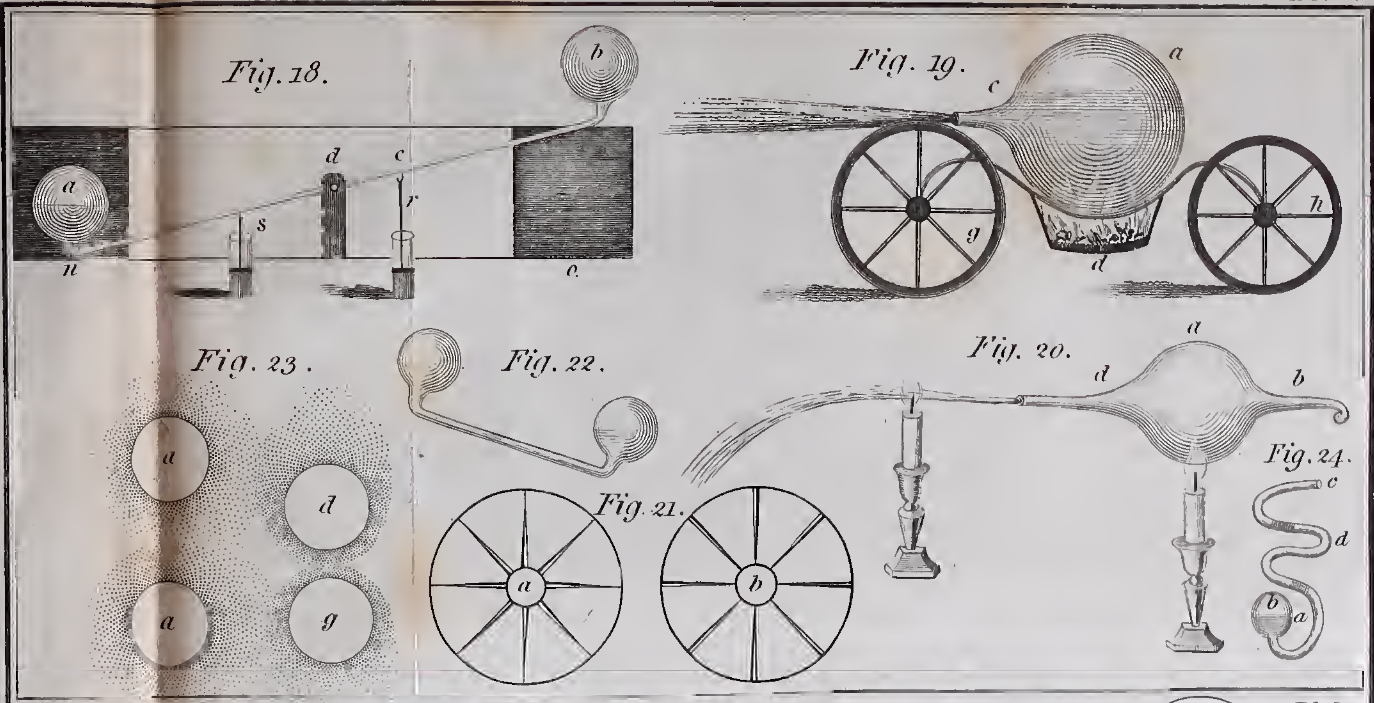
Fig. 16.

Fig. 17.

Mutlow Sculp. Russel Ct.

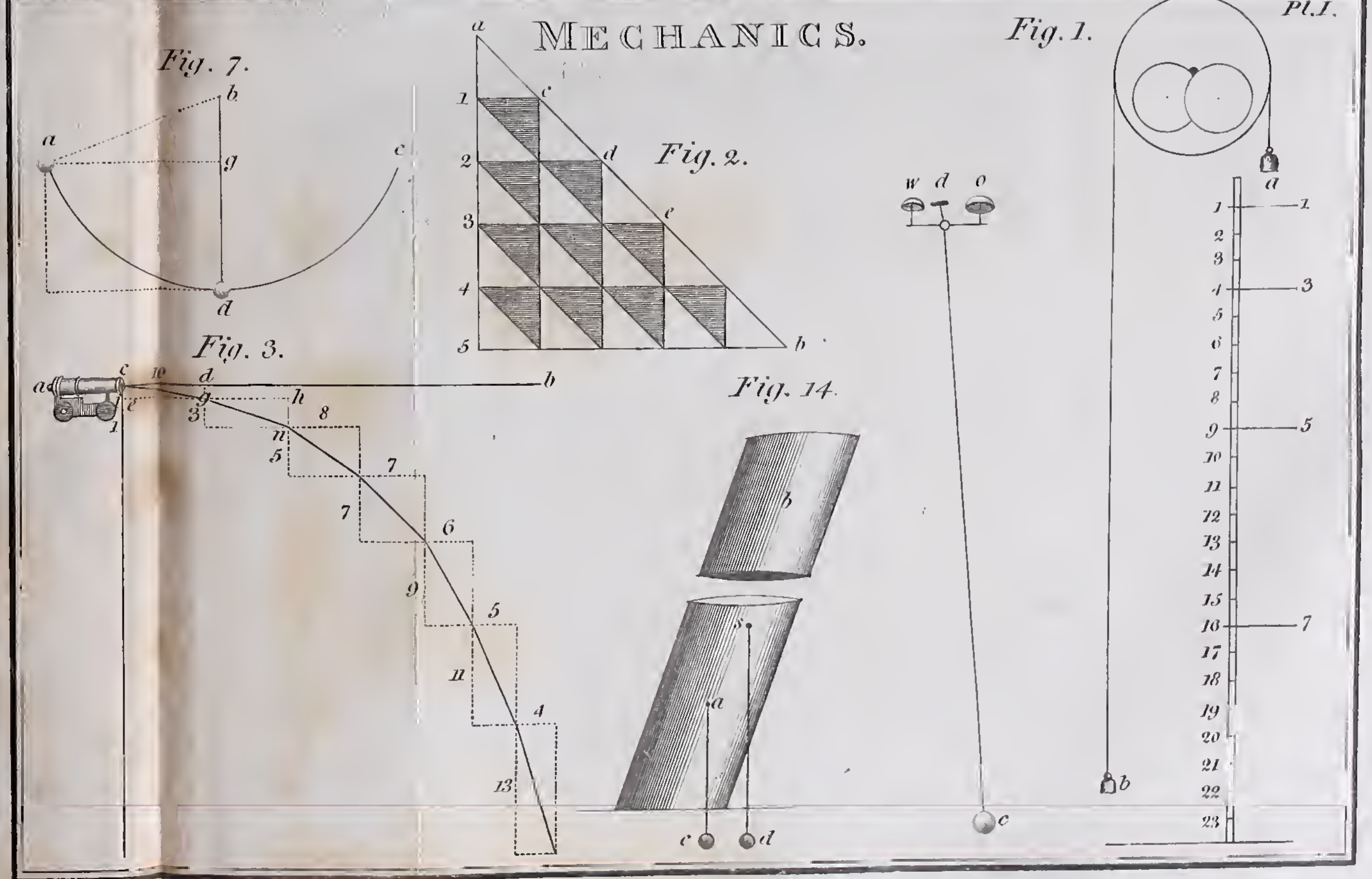
EFFECTS of HEAT.

Pl. V.



MECHANICS.

Pl. I.



Barlow sculp.

MAGNETISM.

Pl. VI


Fig. 1


Fig. 2

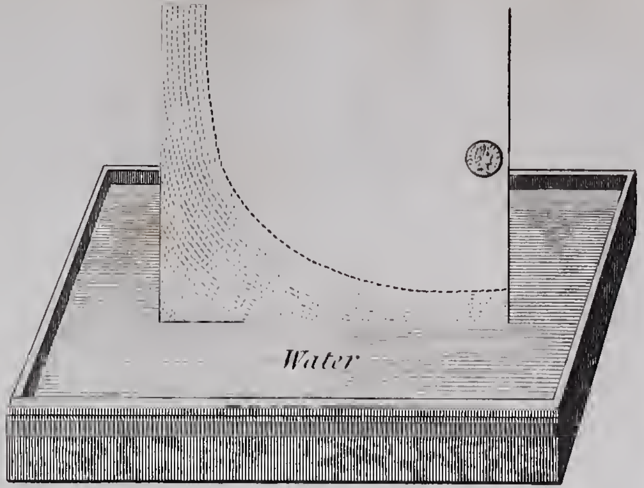

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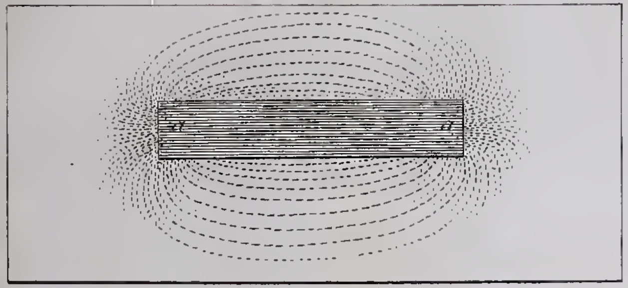
Fig. 3.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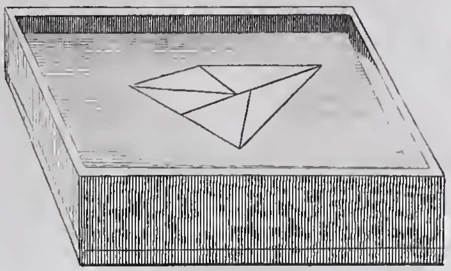
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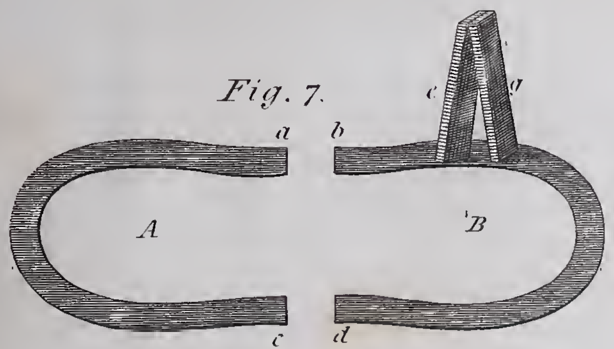
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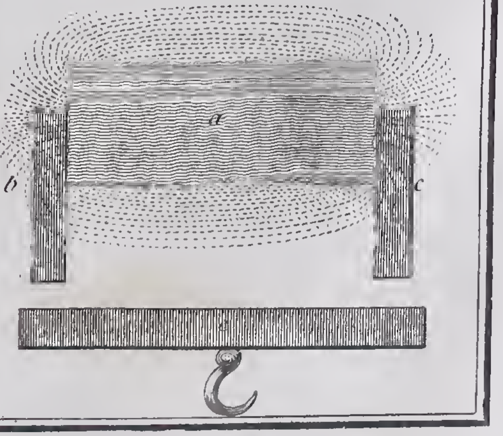
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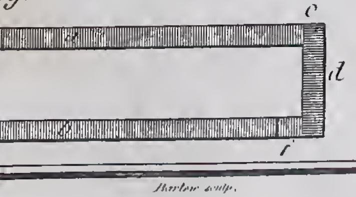
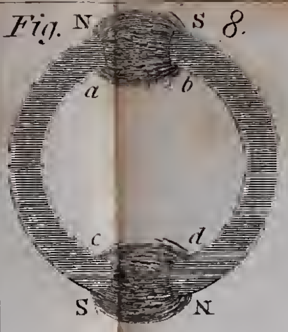


Fig. 8.

Barlow sculp.

Fig. 8.



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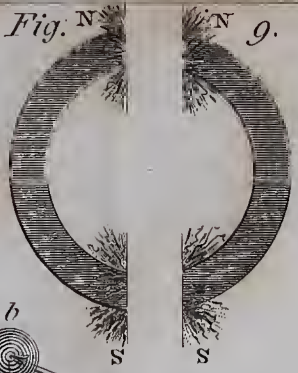

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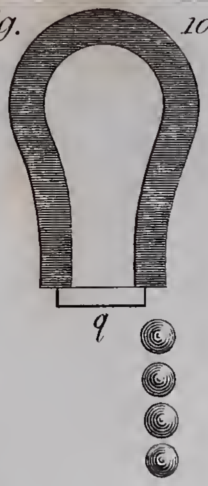

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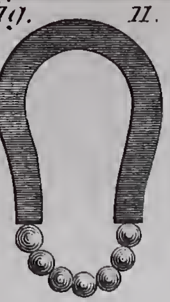
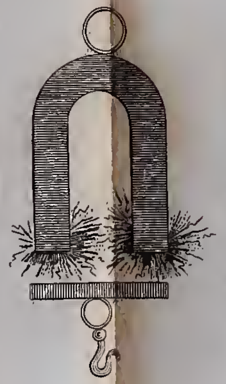




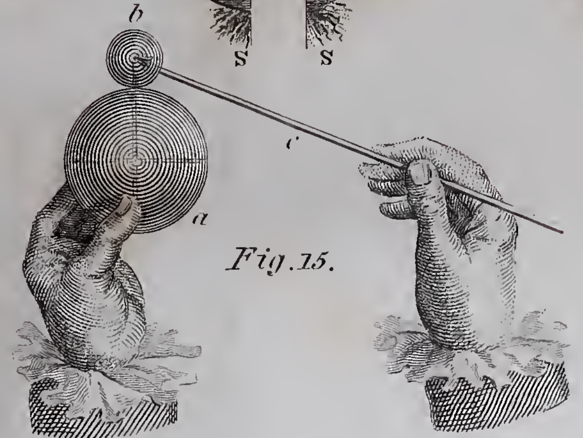
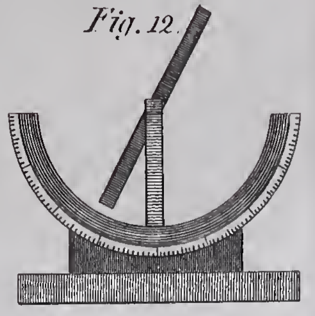


Fig. 15.

Fig. 12.



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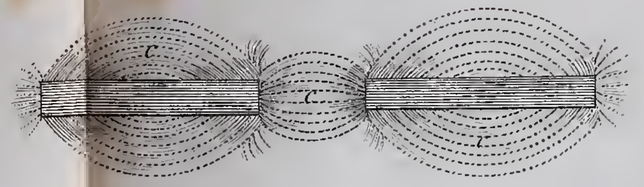

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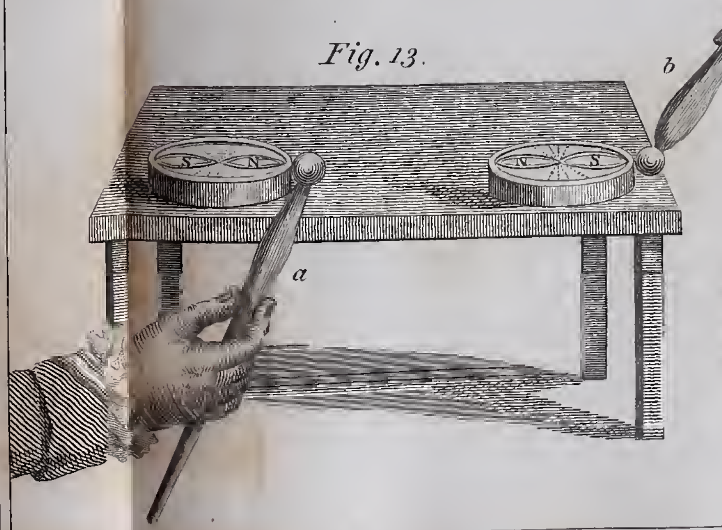

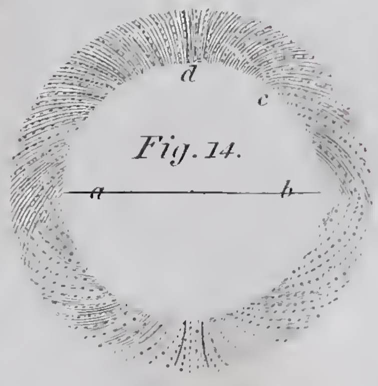

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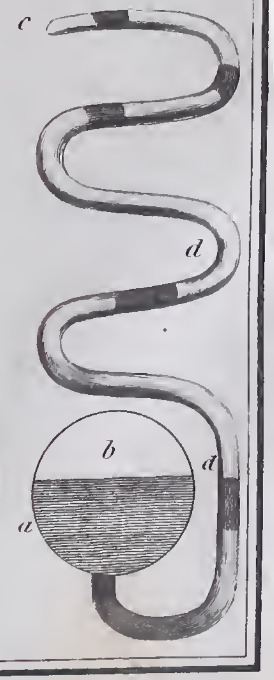

Barlow sculp.

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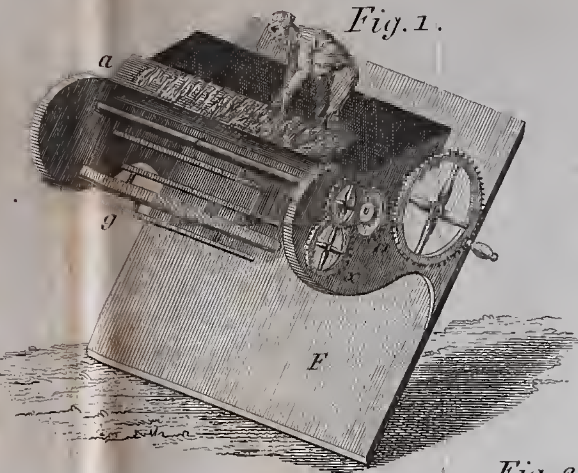

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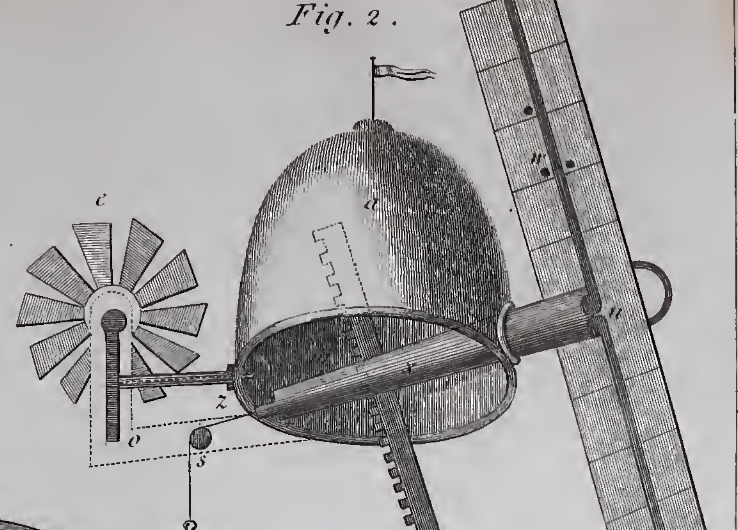

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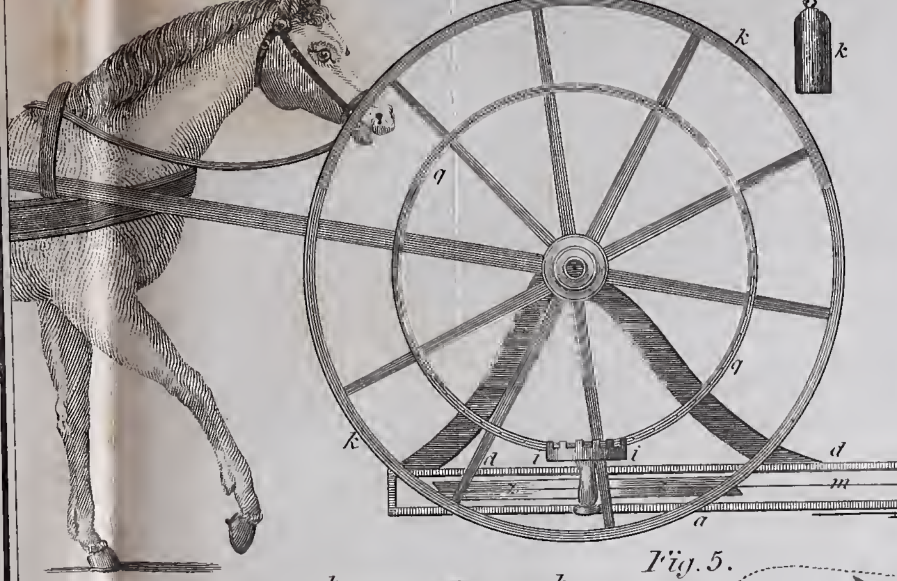

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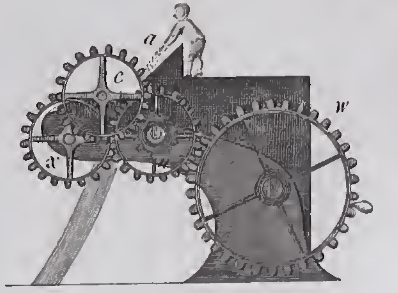

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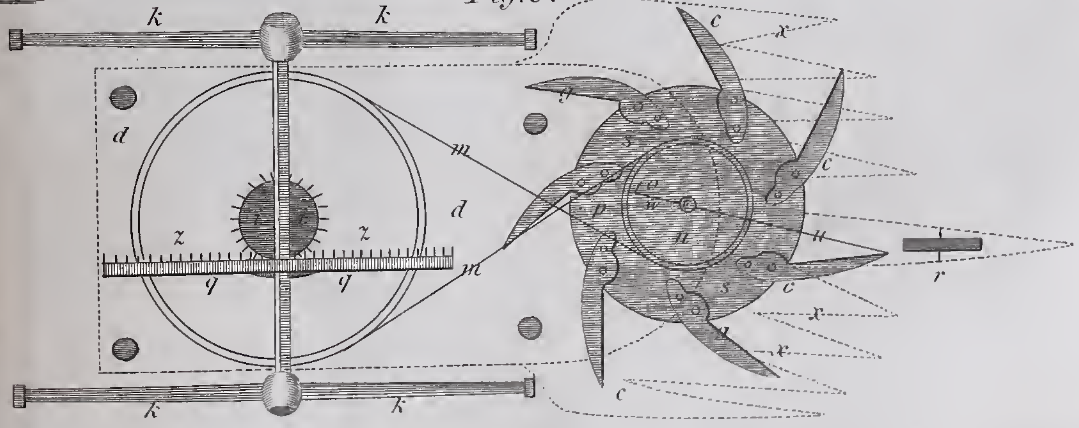

Barlow sculp.t

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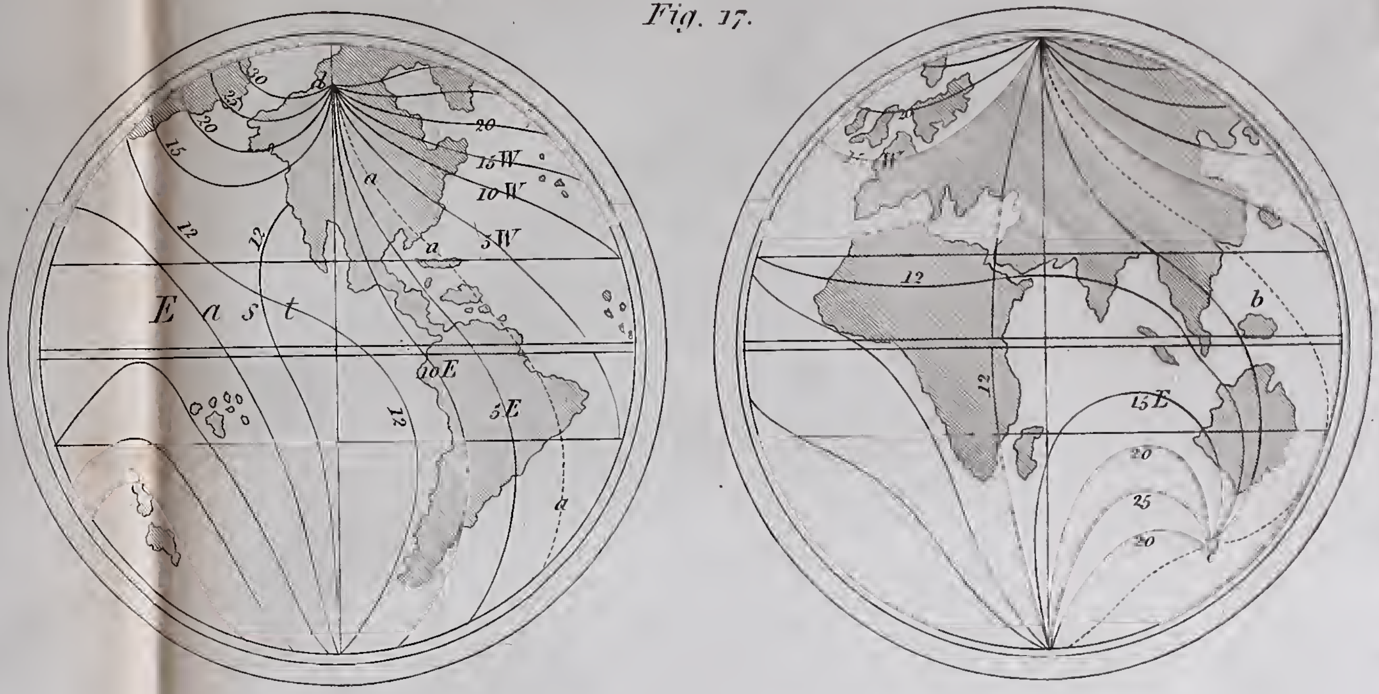

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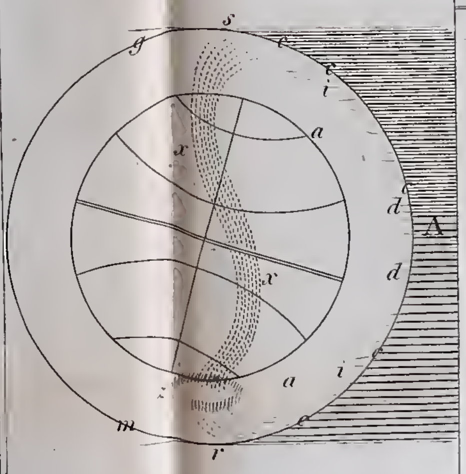

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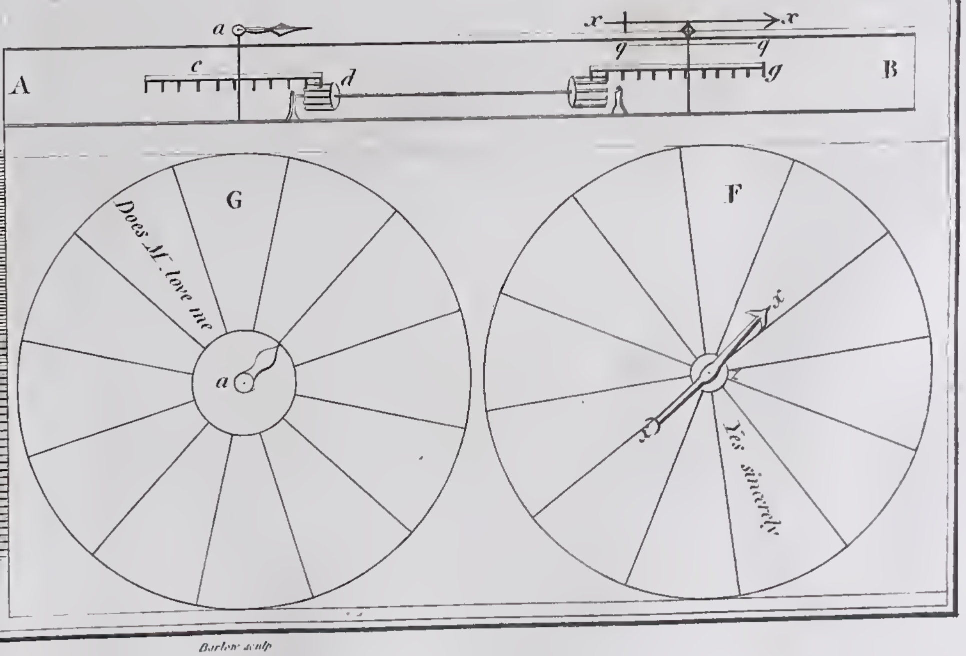

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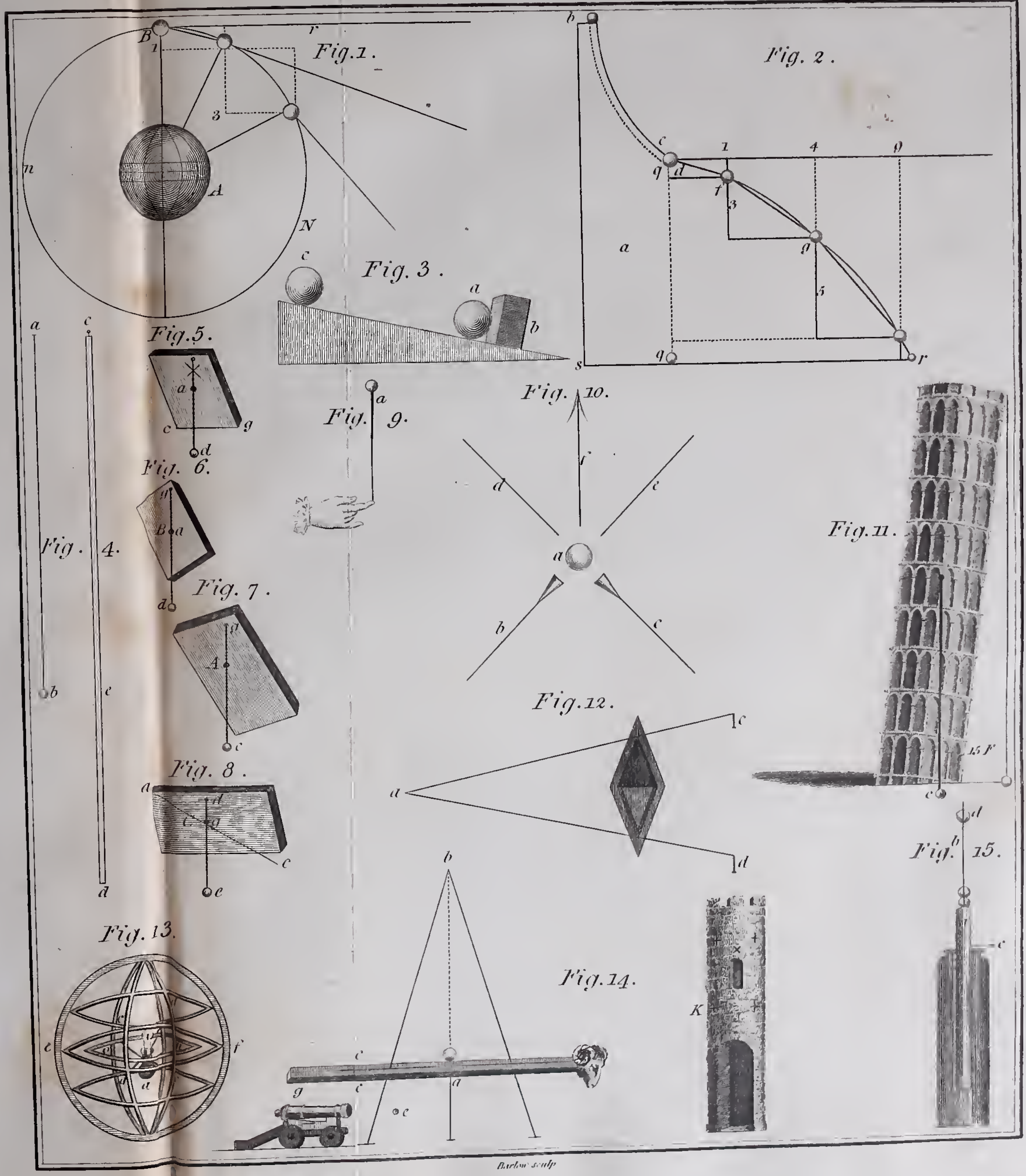

Barlow sculp

MECHANICS. Pl. X.

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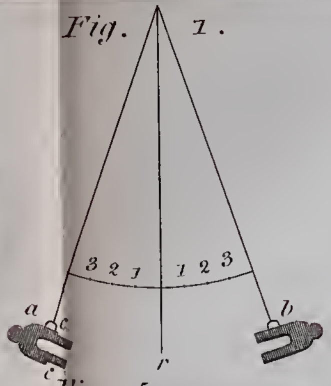

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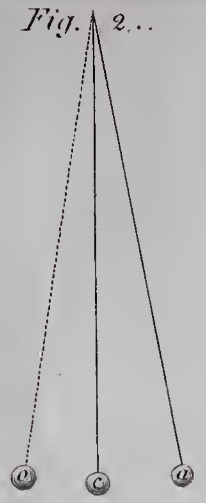

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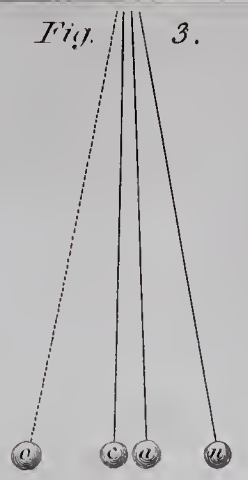

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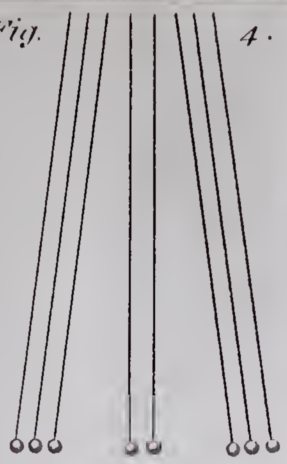

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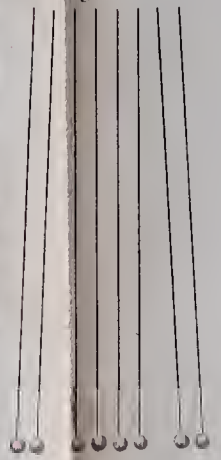

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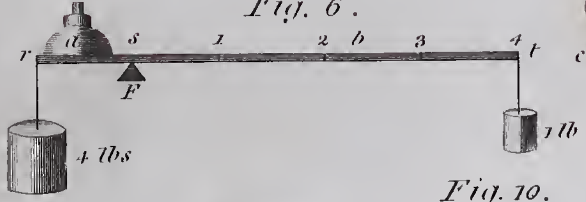

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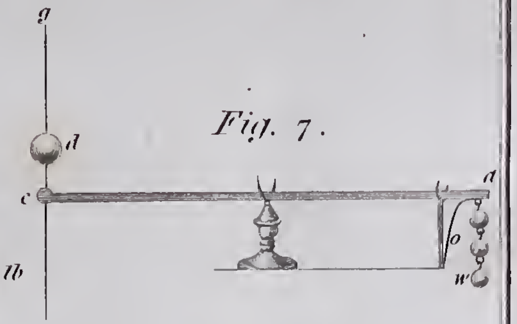

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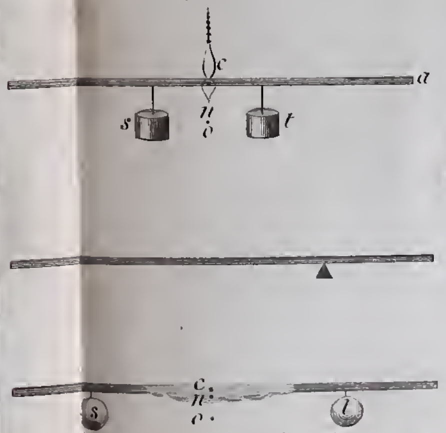

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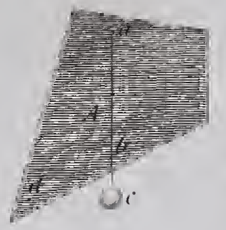

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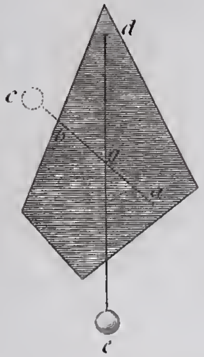

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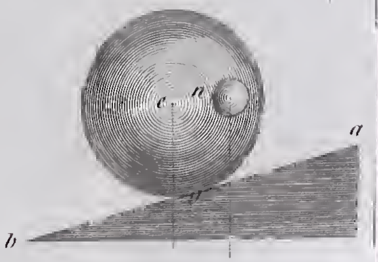

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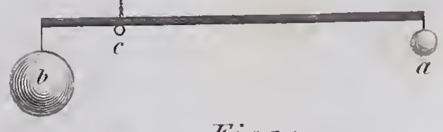
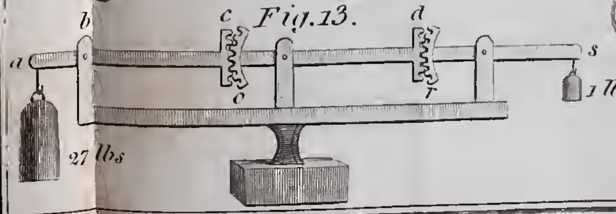


Fig. 13.



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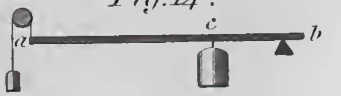
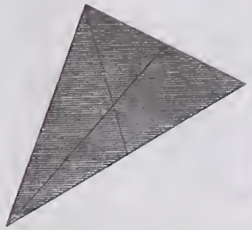
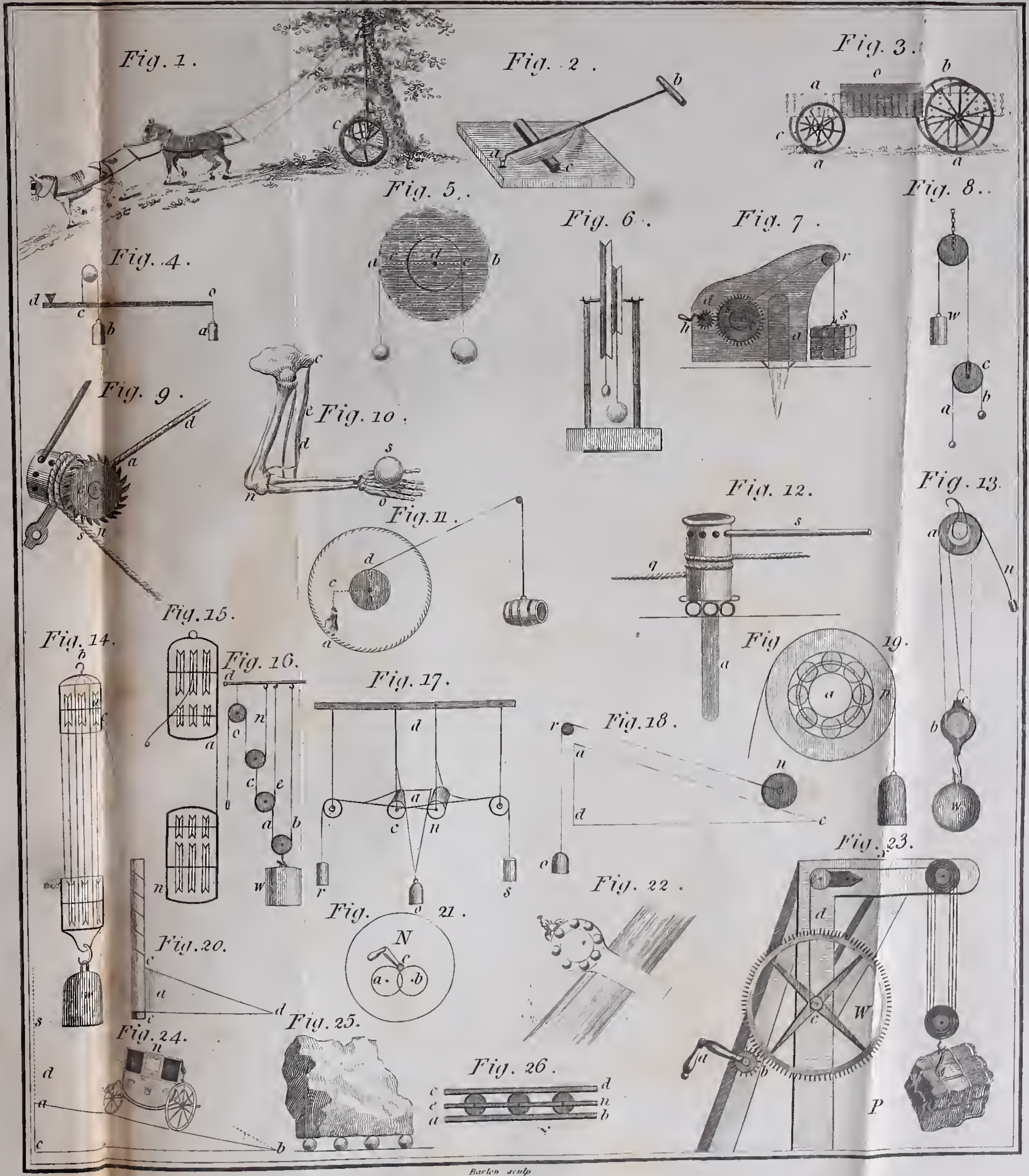




Barlow sculp.

MECHANICS.

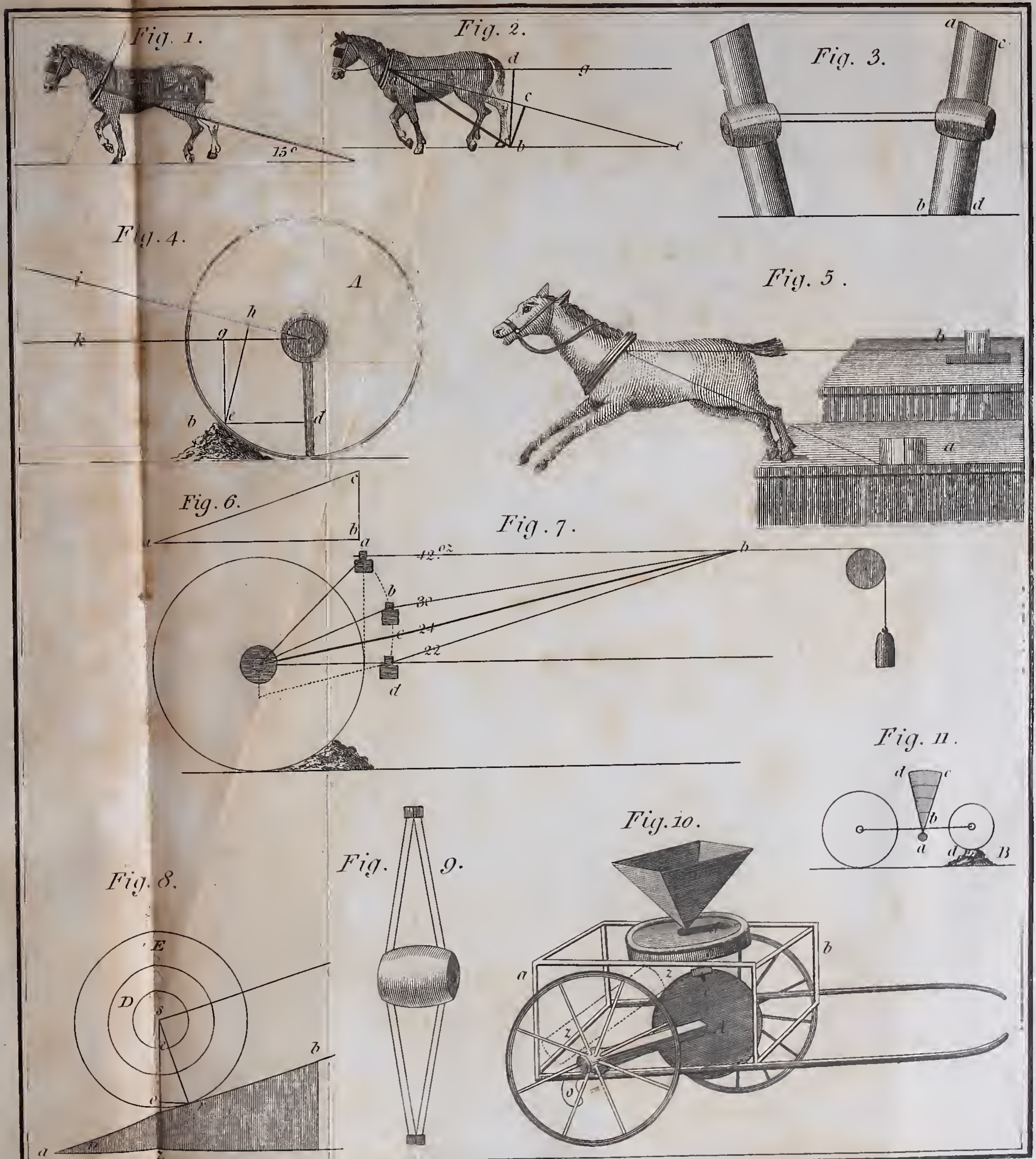
Pl. XI.



Barlow sculp

WHEEL CARRIAGES.

Pl. XIII.



Barlow sculp

WHEEL CARRIAGES.

Pl. XIV

Fig. 1.

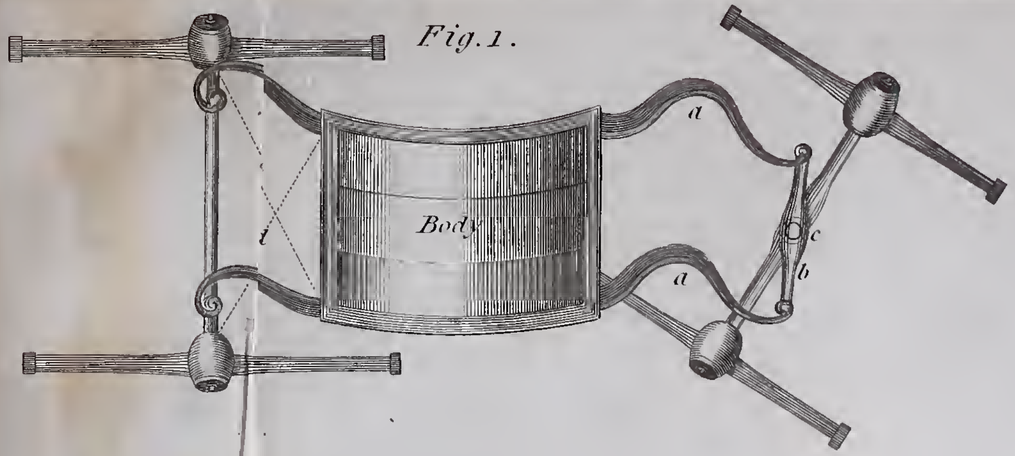
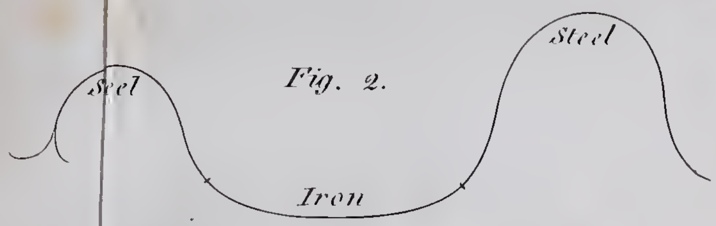
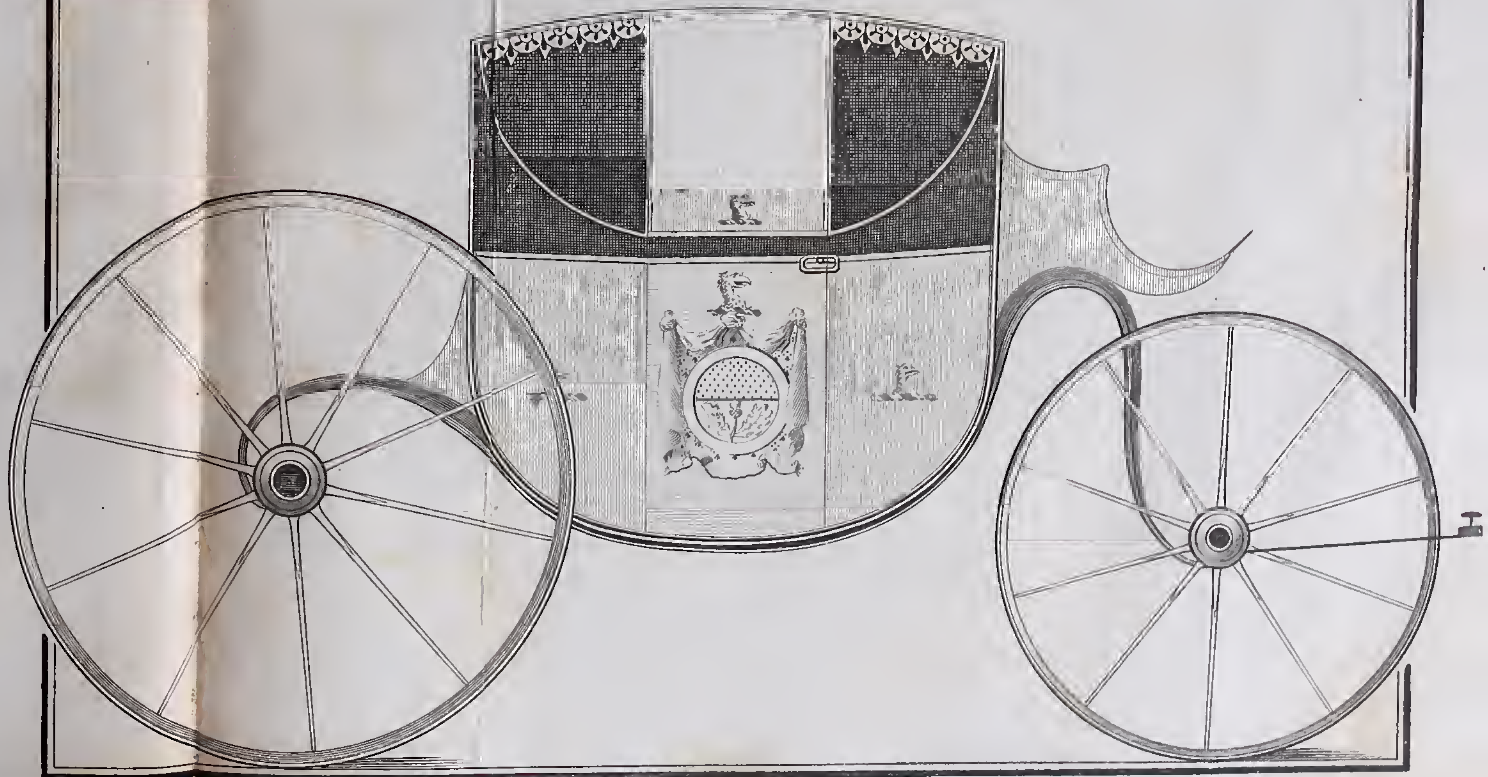


Fig. 2.





Barlow sculp.

CHEMISTRY.

Pl. XV.

Fig. 1.

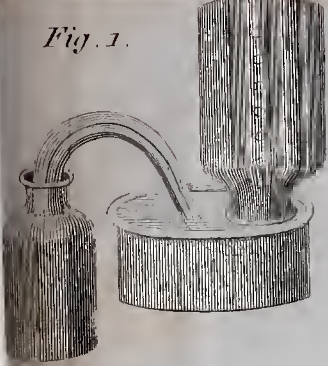


Fig. 2.

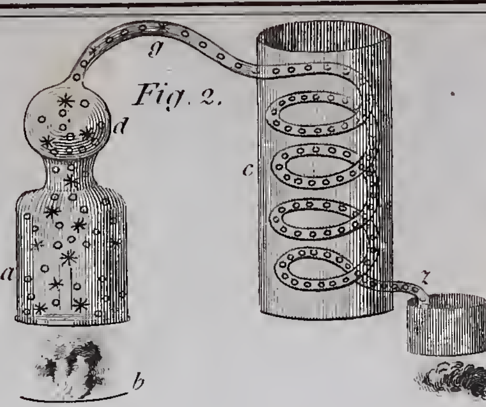


Fig. 3.

Fig. 4.

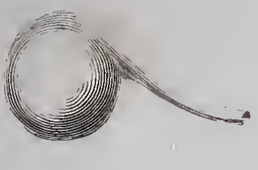


Fig. 5.

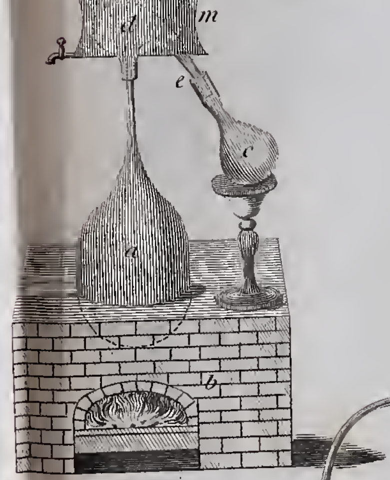


Fig. 6.

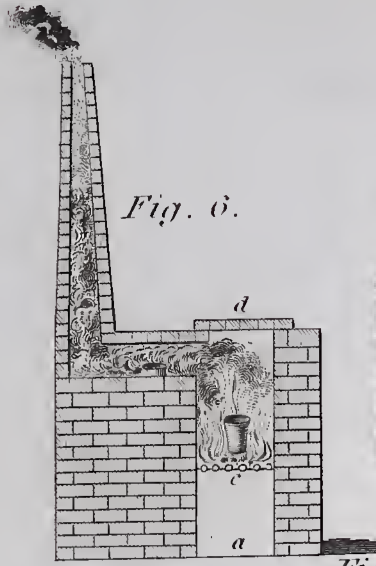


Fig. 7.

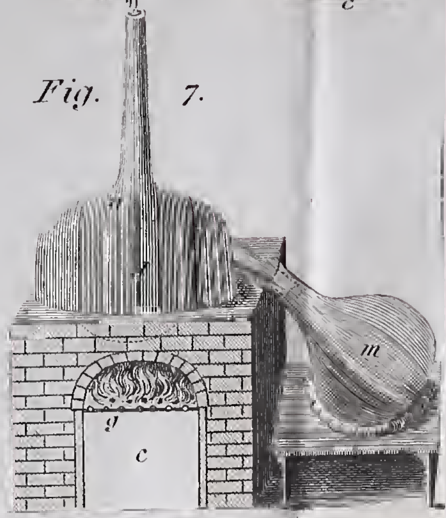


Fig. 9.

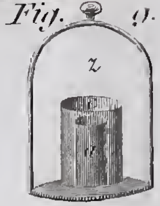
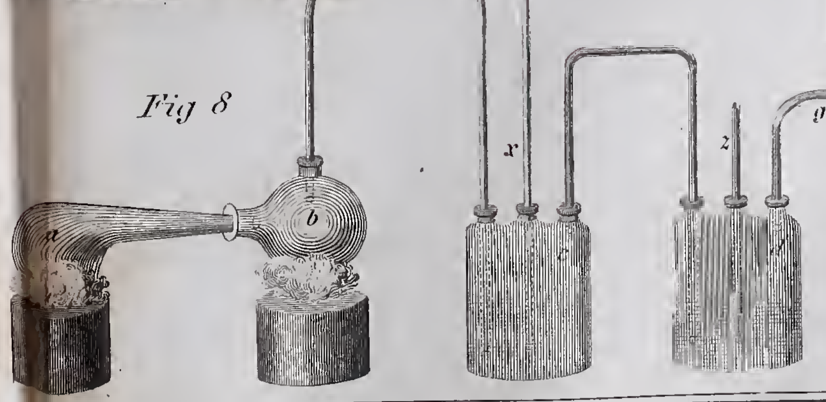


Fig 8



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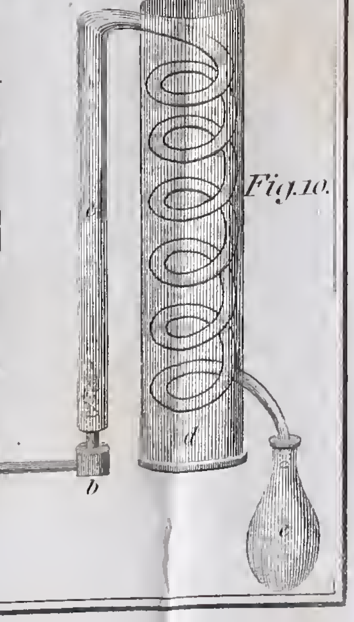
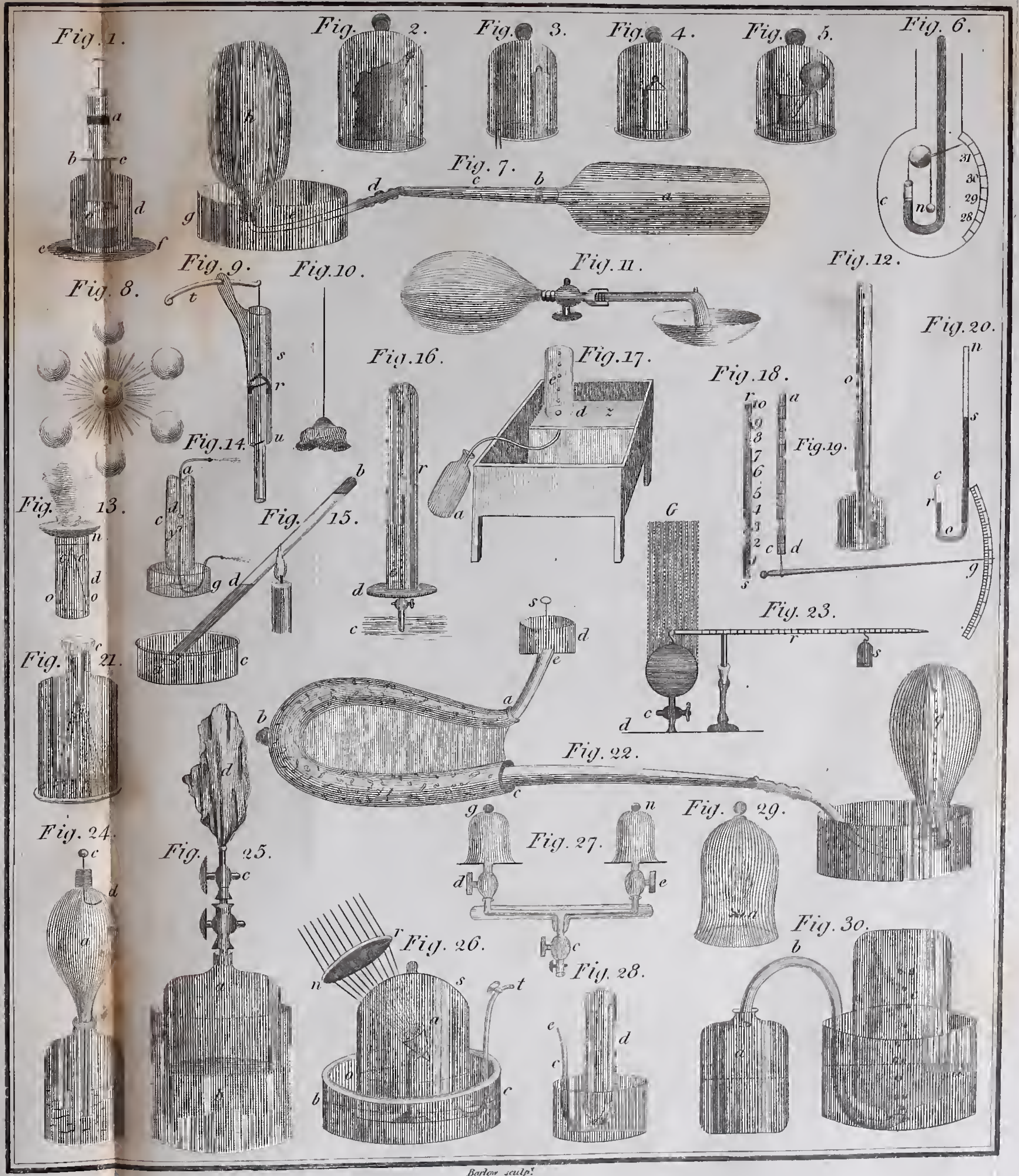


Barlow sculp

PNEUMATICS.

Pl. XVI.



Barlow sculp^t.

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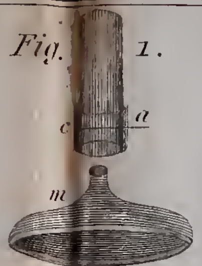

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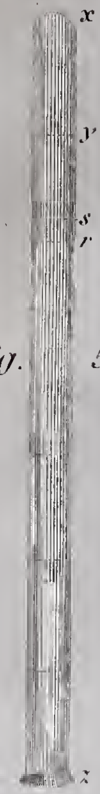
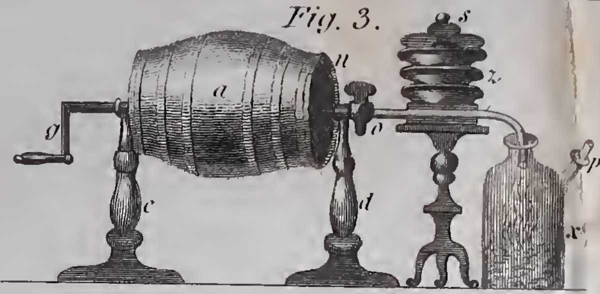


Fig. 2.

Fig. 3.



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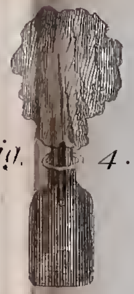

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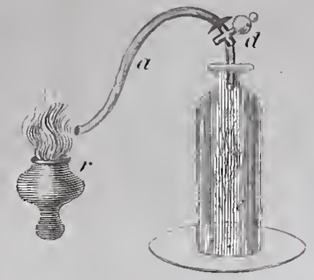

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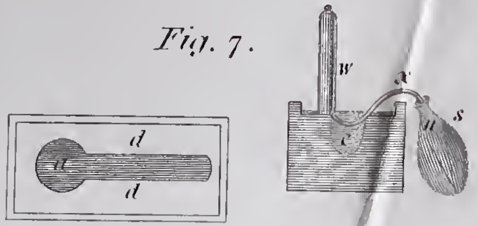

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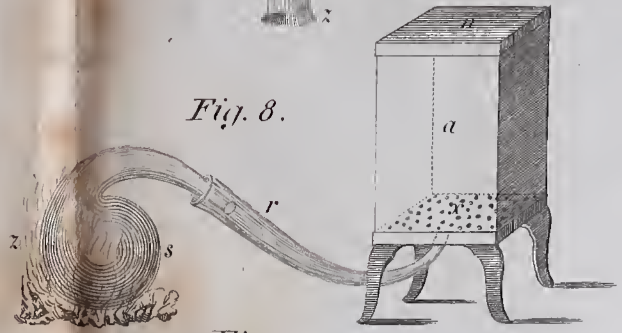

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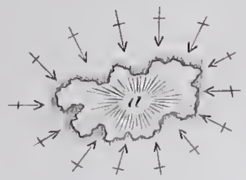

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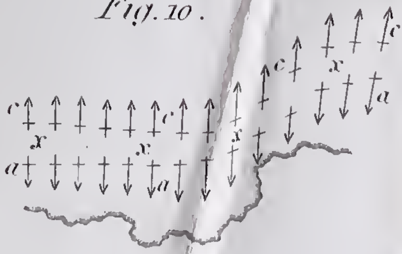
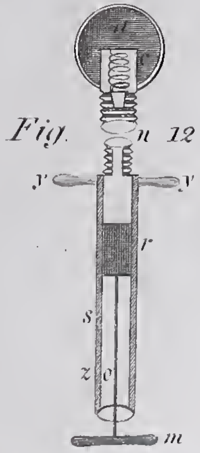


Fig. 11.

Fig. 12.



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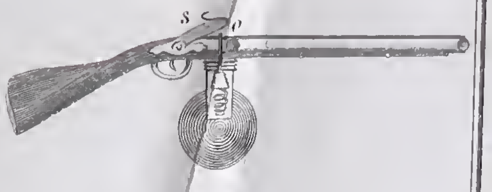
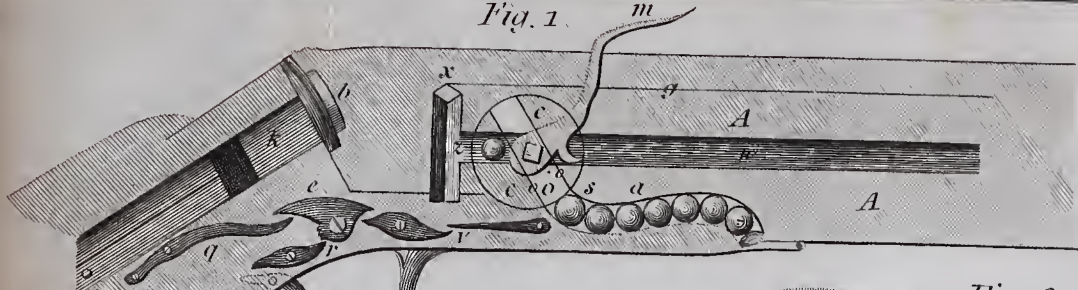


Barlow sculp

PNEUMATICS.

Pl. XVIII.

Fig. 1.



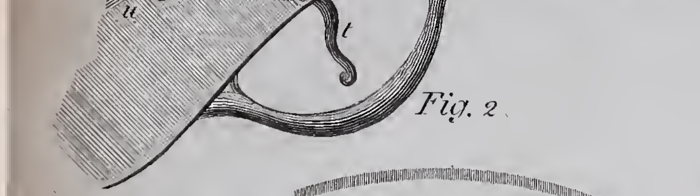
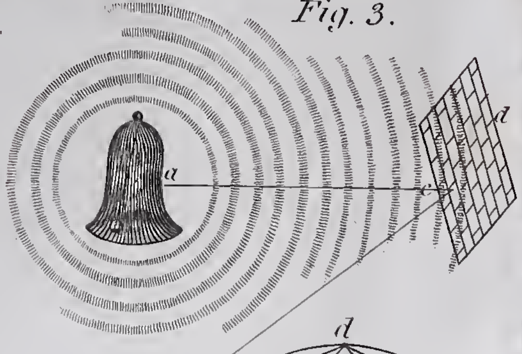
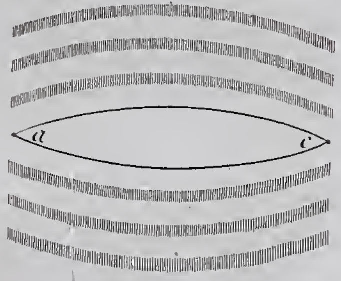


Fig. 2.

Fig. 3.





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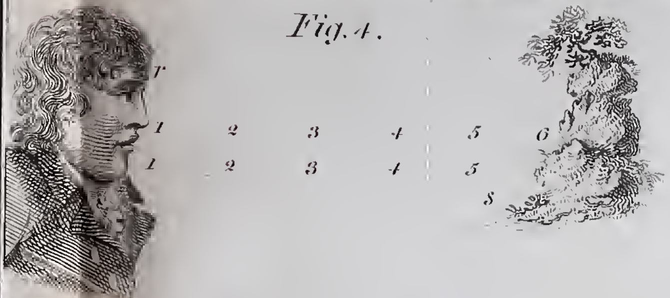


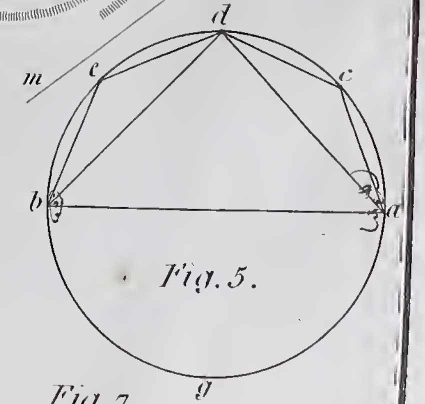


Fig. 5.

Fig. 7.

Fig. 6.

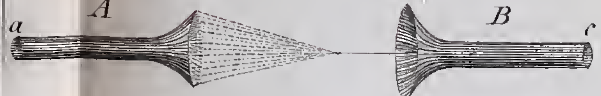
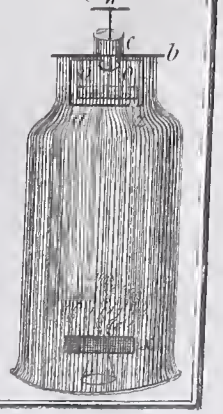


Fig. 9.

Fig. 10.



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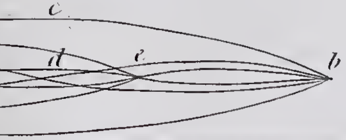
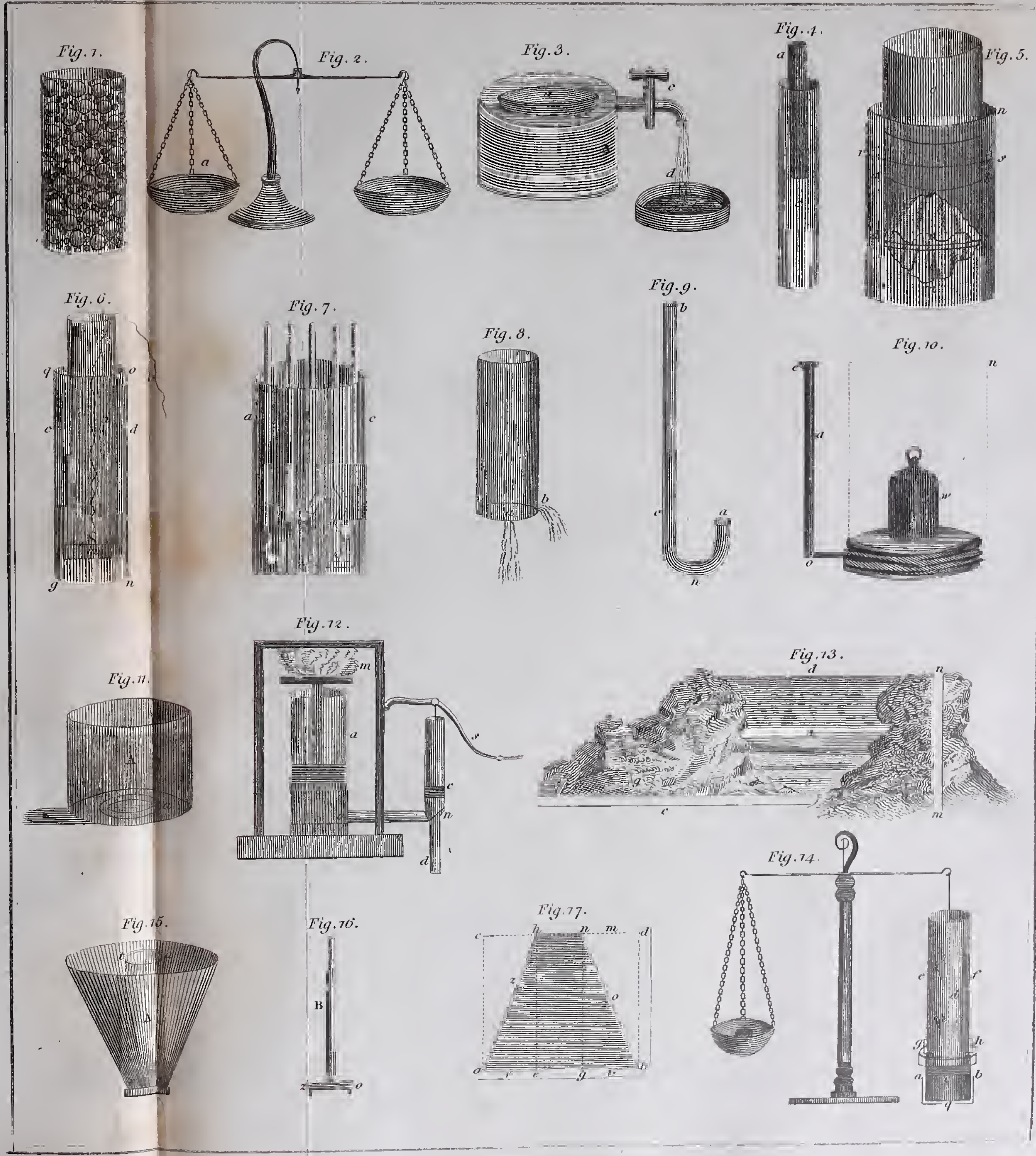


Barlow sculp.

HYDROSTATICS.

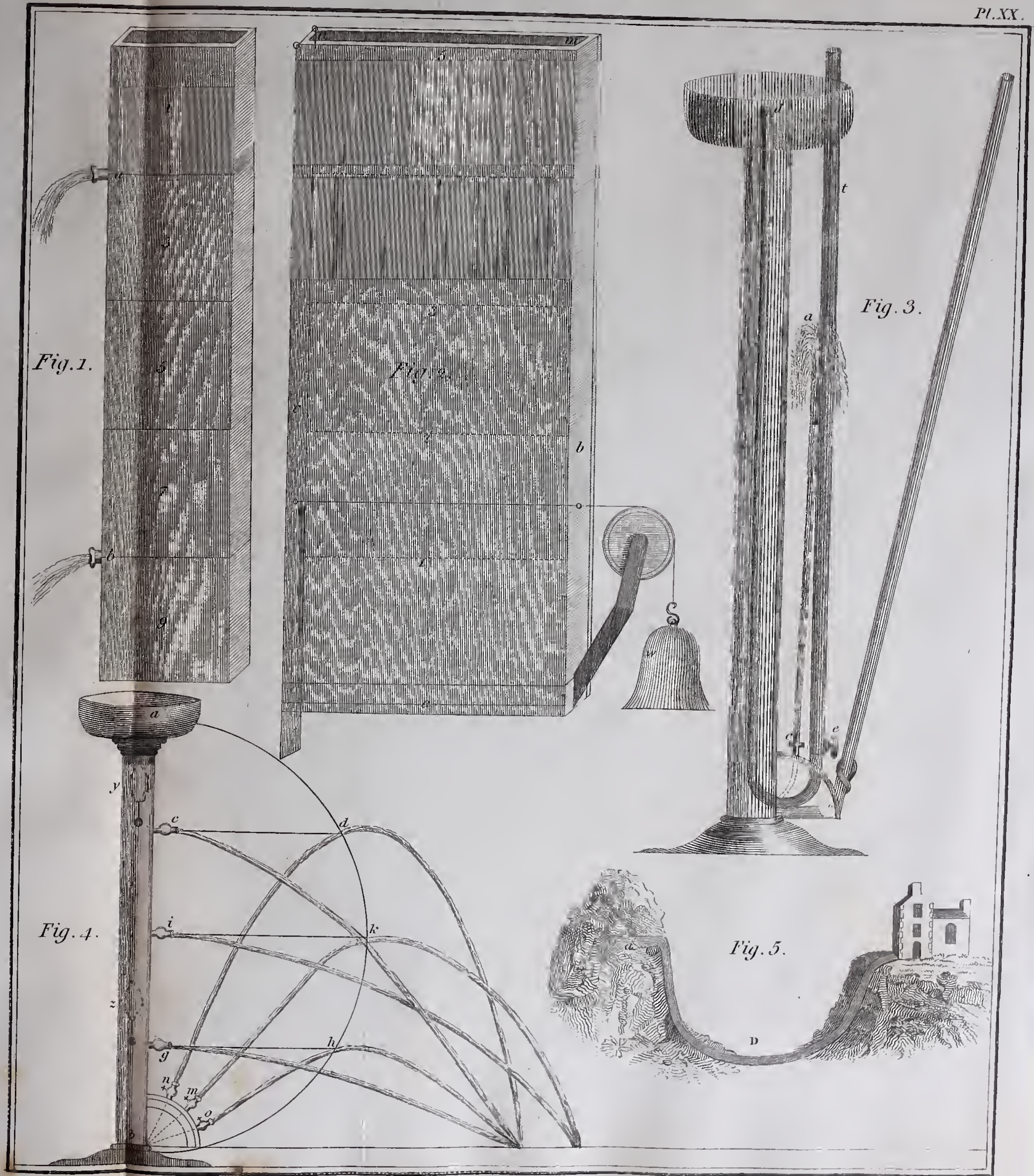
Pl. XIX.



Mutlow Sc. Ruſsell Court.

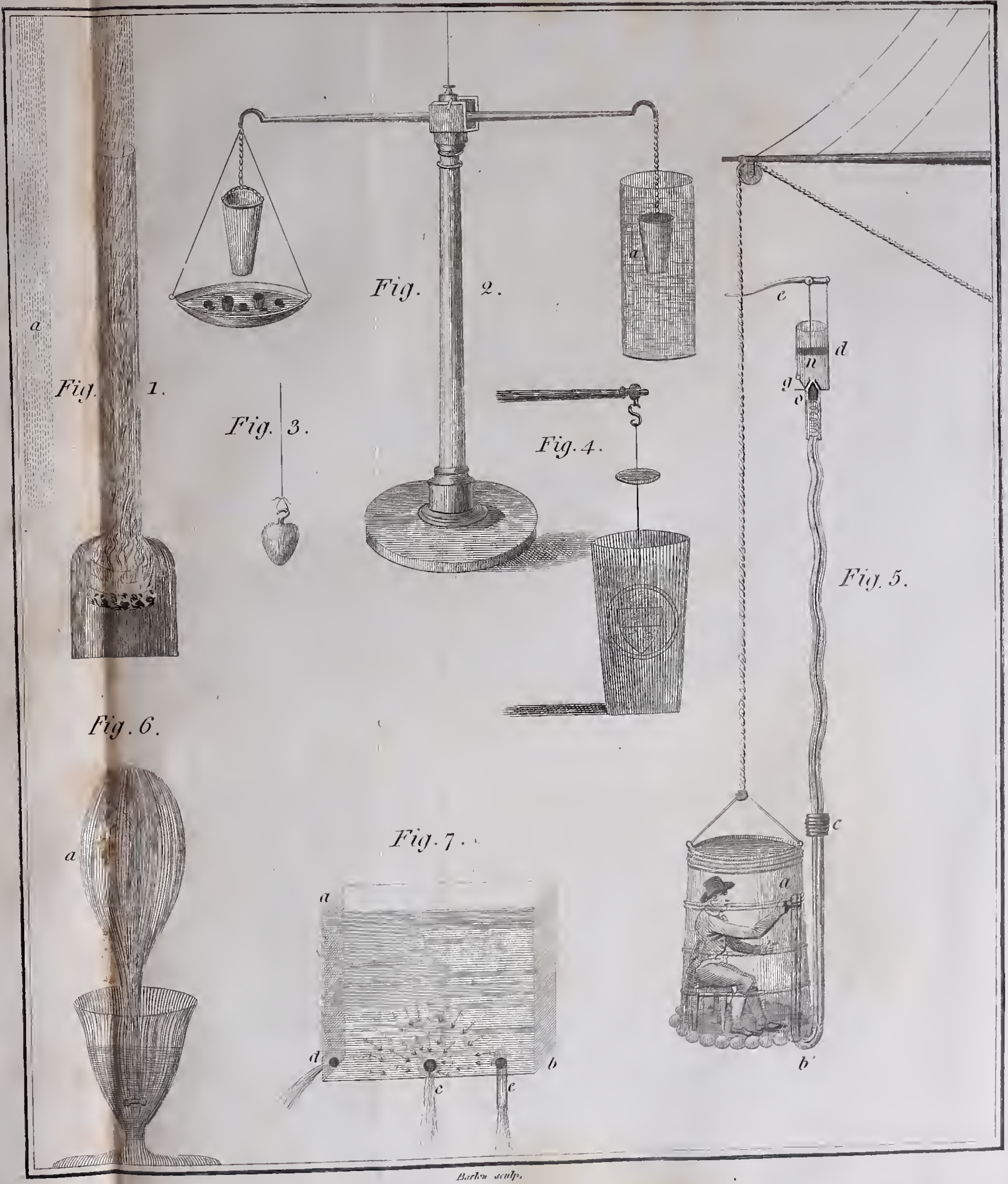
HYDROSTATICS.

Pl. XX.



HYDROSTATICS.

Pl. XXI.



Barlow sculp.

HYDROSTATICS.

Pl. XXII.

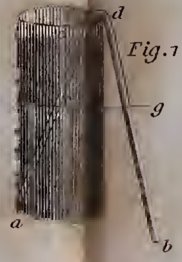


Fig. 1.

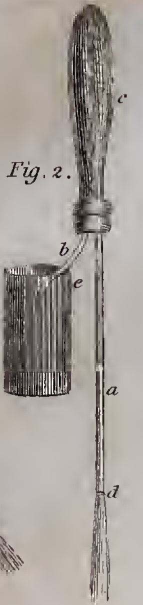


Fig. 2.

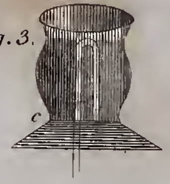


Fig. 3.


Fig. 4.

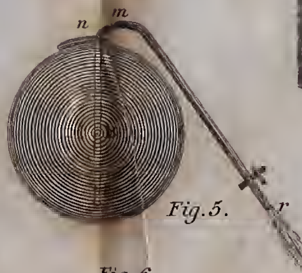


Fig. 5.

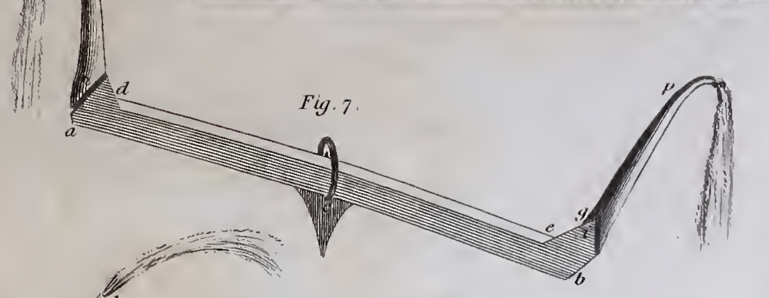


Fig. 7.


Fig. 6.

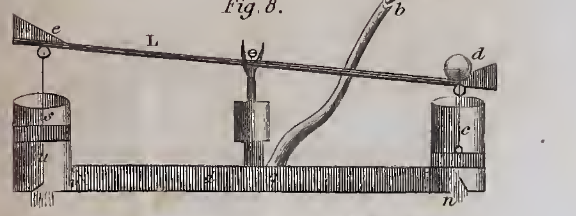


Fig. 8.

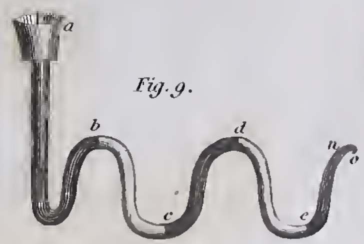


Fig. 9.

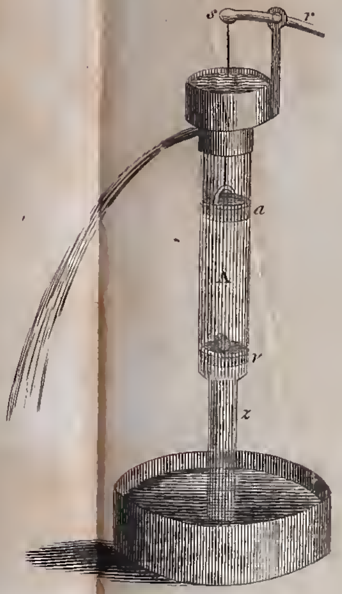


Fig. 10.

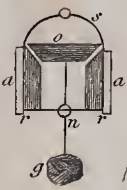


Fig. 11.

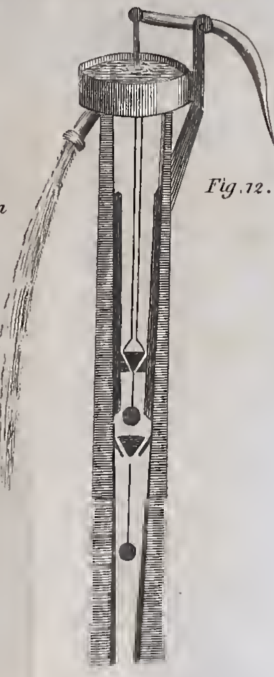


Fig. 12.

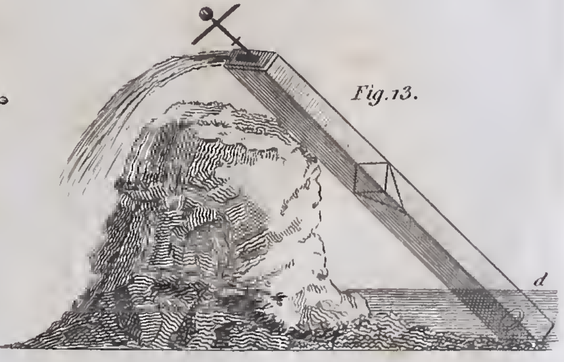


Fig. 13.

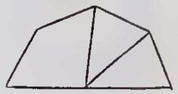


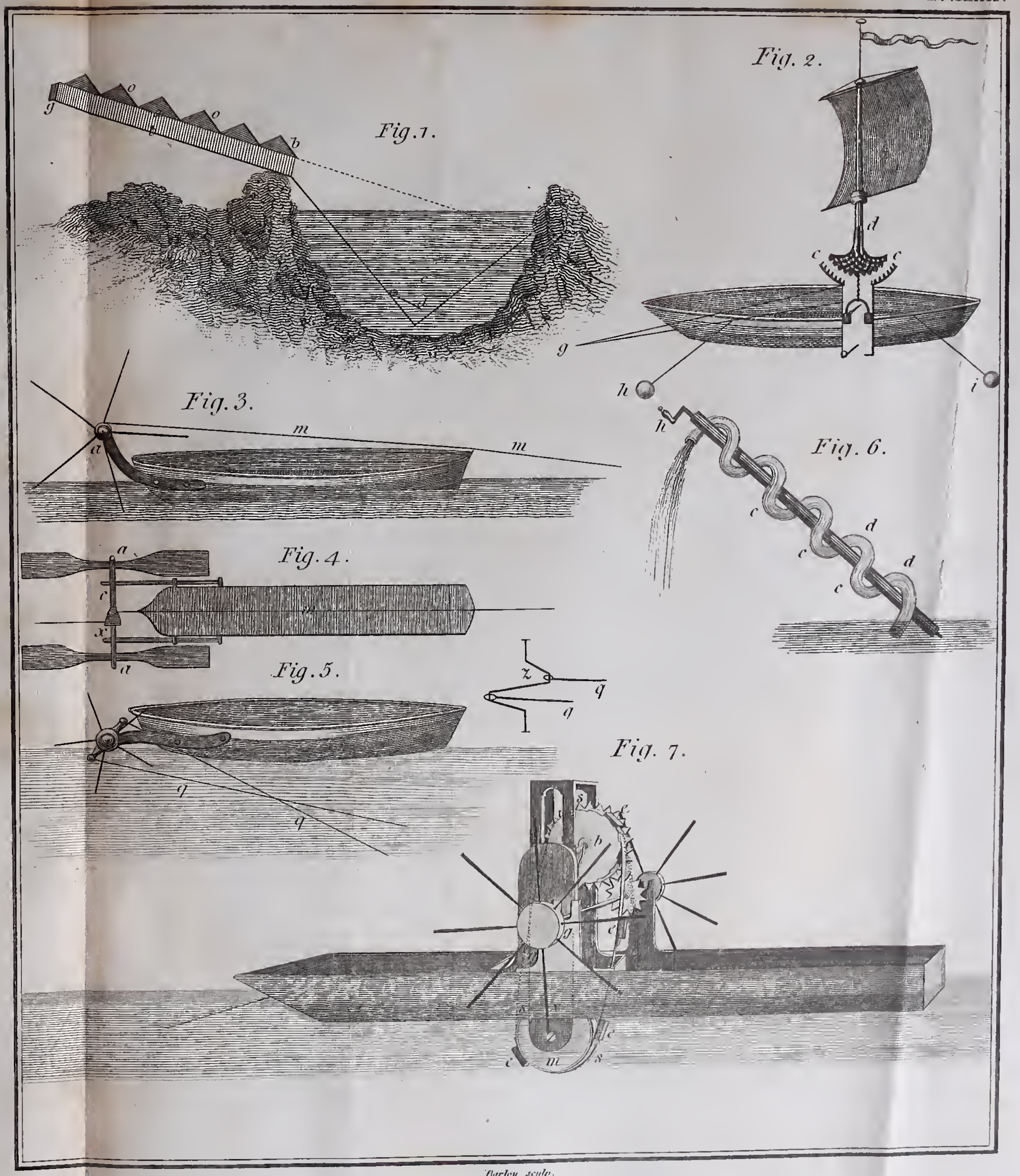
Fig. 14.


Fig. 15.

Mutlow Sc Ruſsell Court

HYDRAULICS.

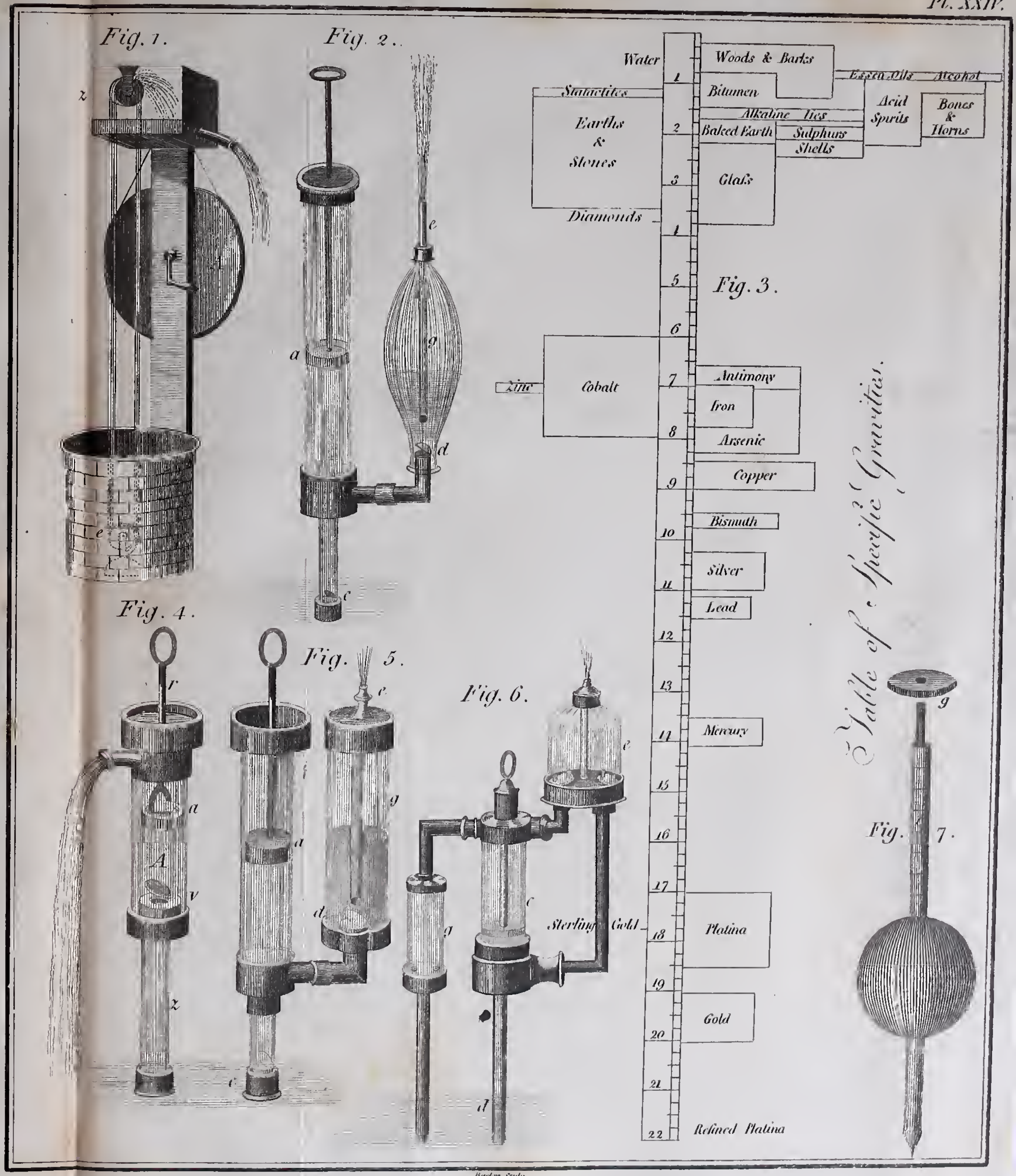
Pl. XXIII.



Barlow sculp.

HYDRAULICS.

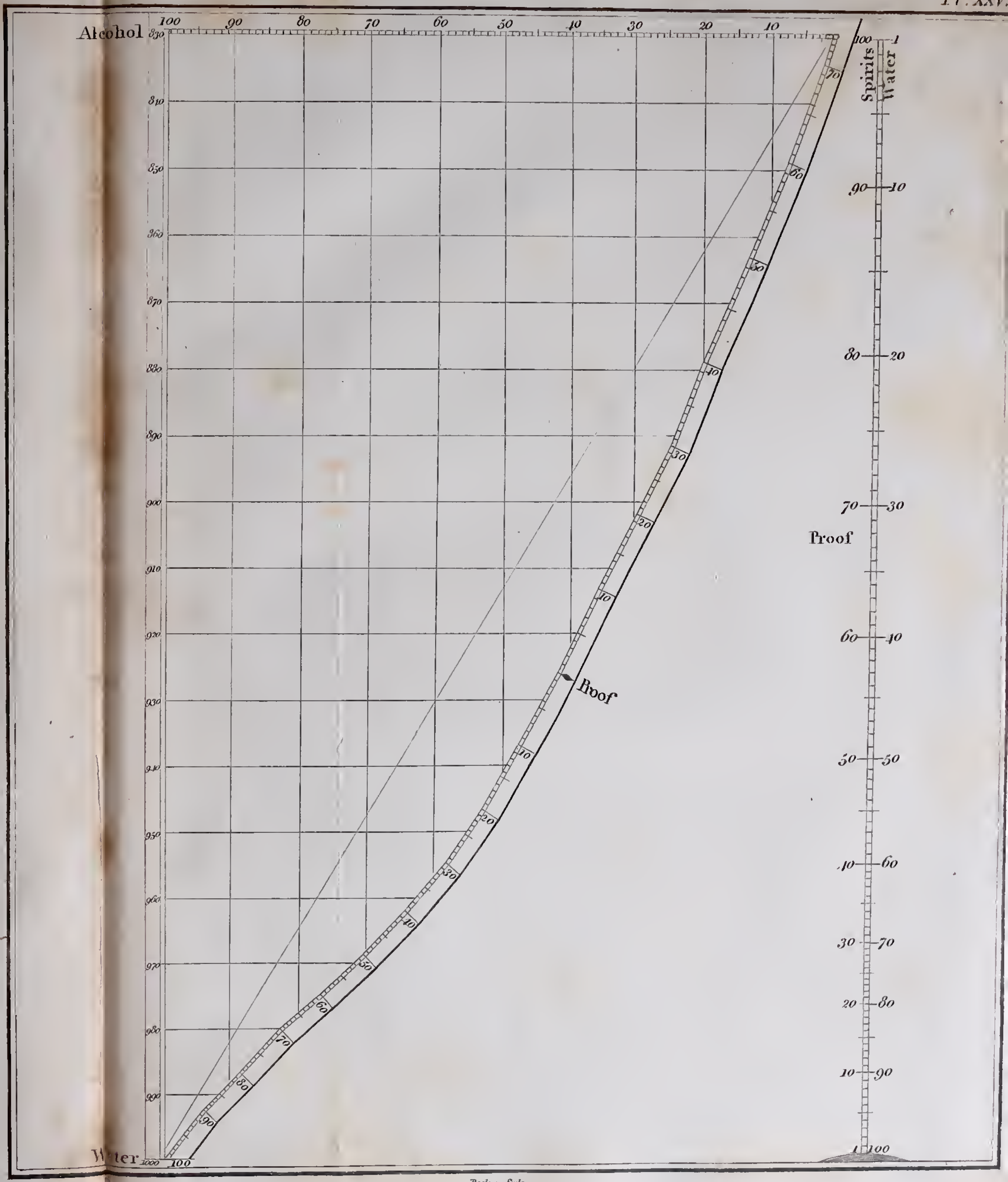
Pl. XXIV.



Barlow Sculp.

HYDROMETRICAL TABLE.

Pl. XXV



Barlow Sculp.

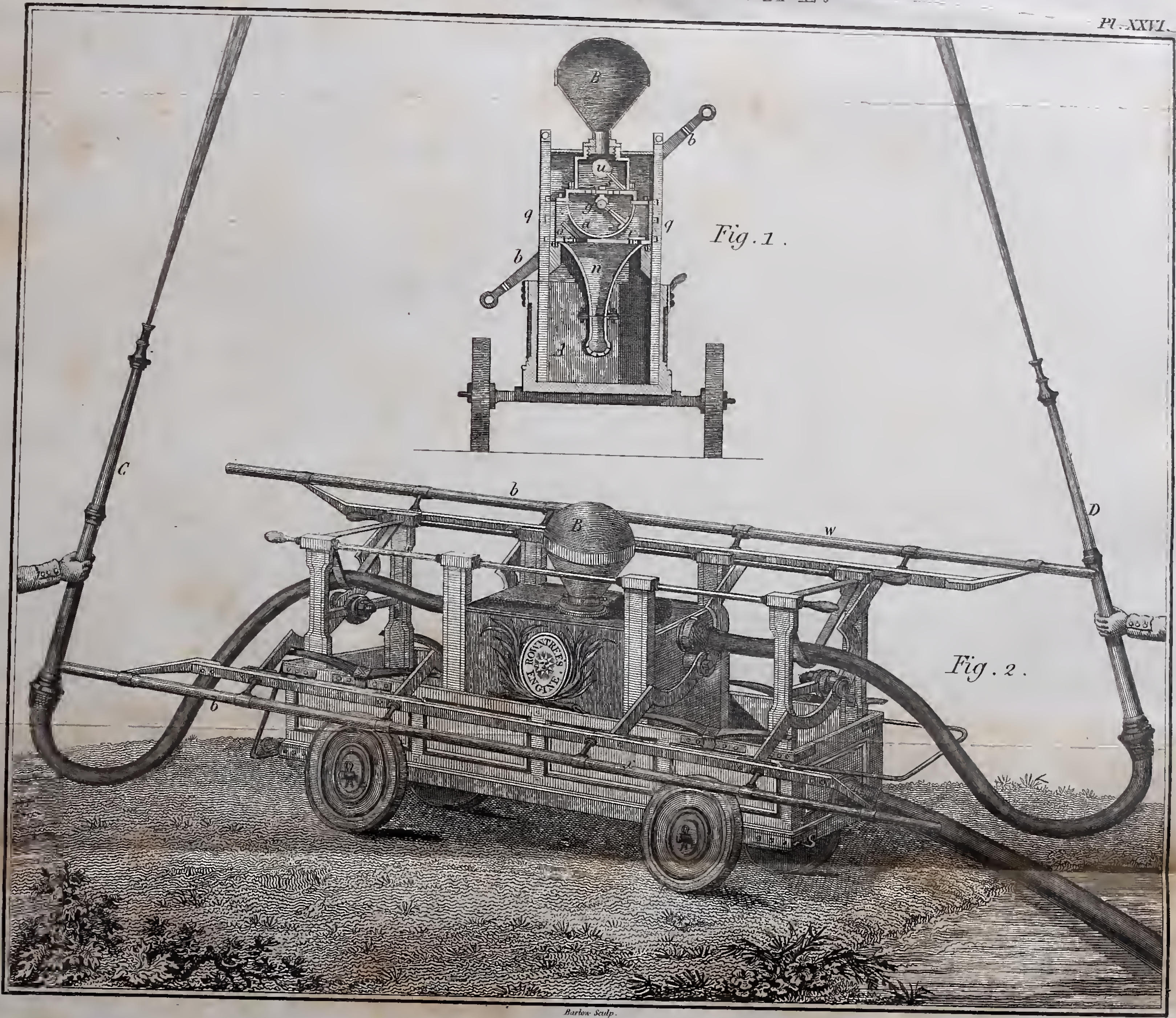
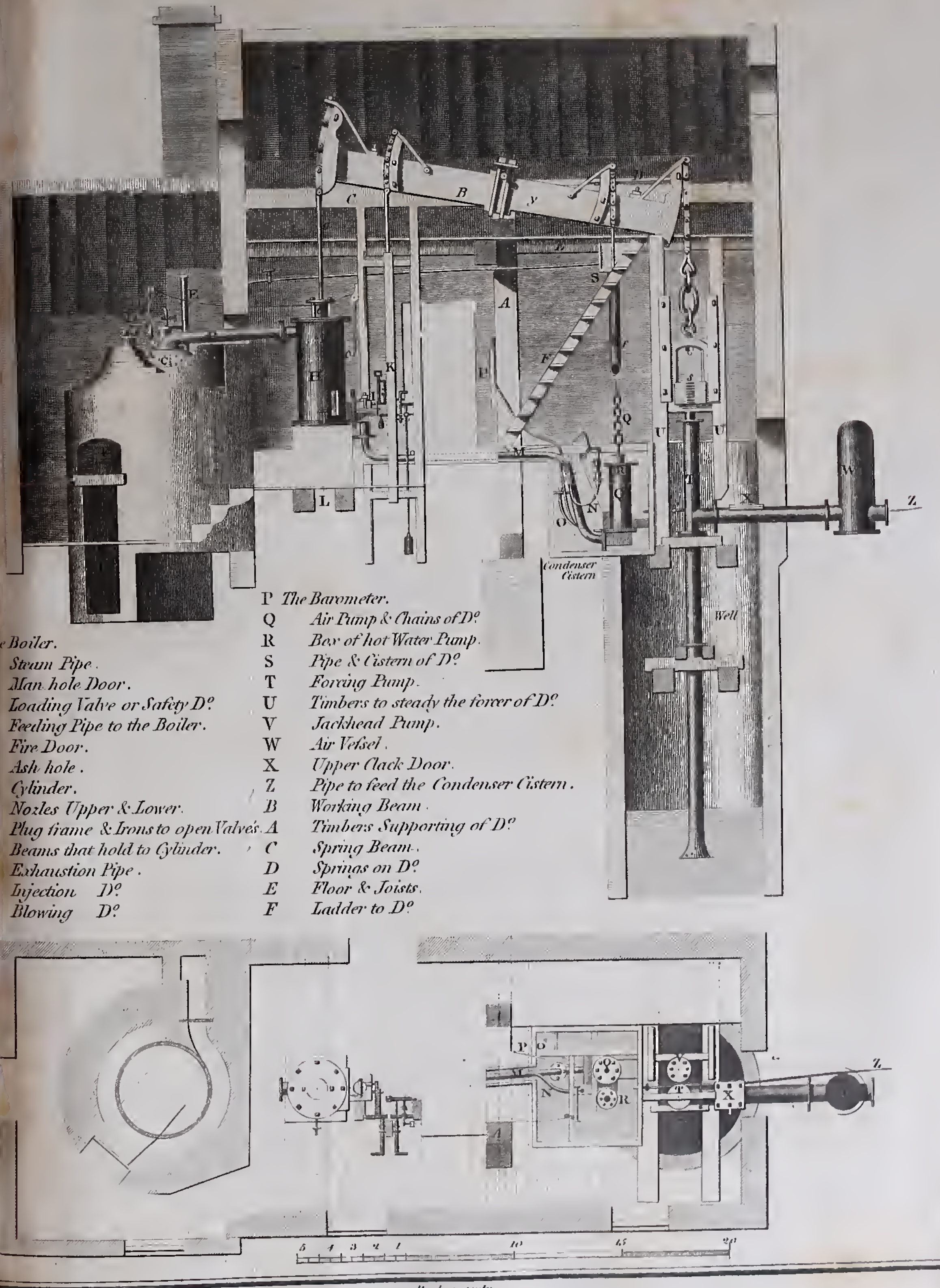


Fig. 1.

Fig. 2.

Barlow Sculp.

Boulton & Co.s new invented patent Fire Engine.

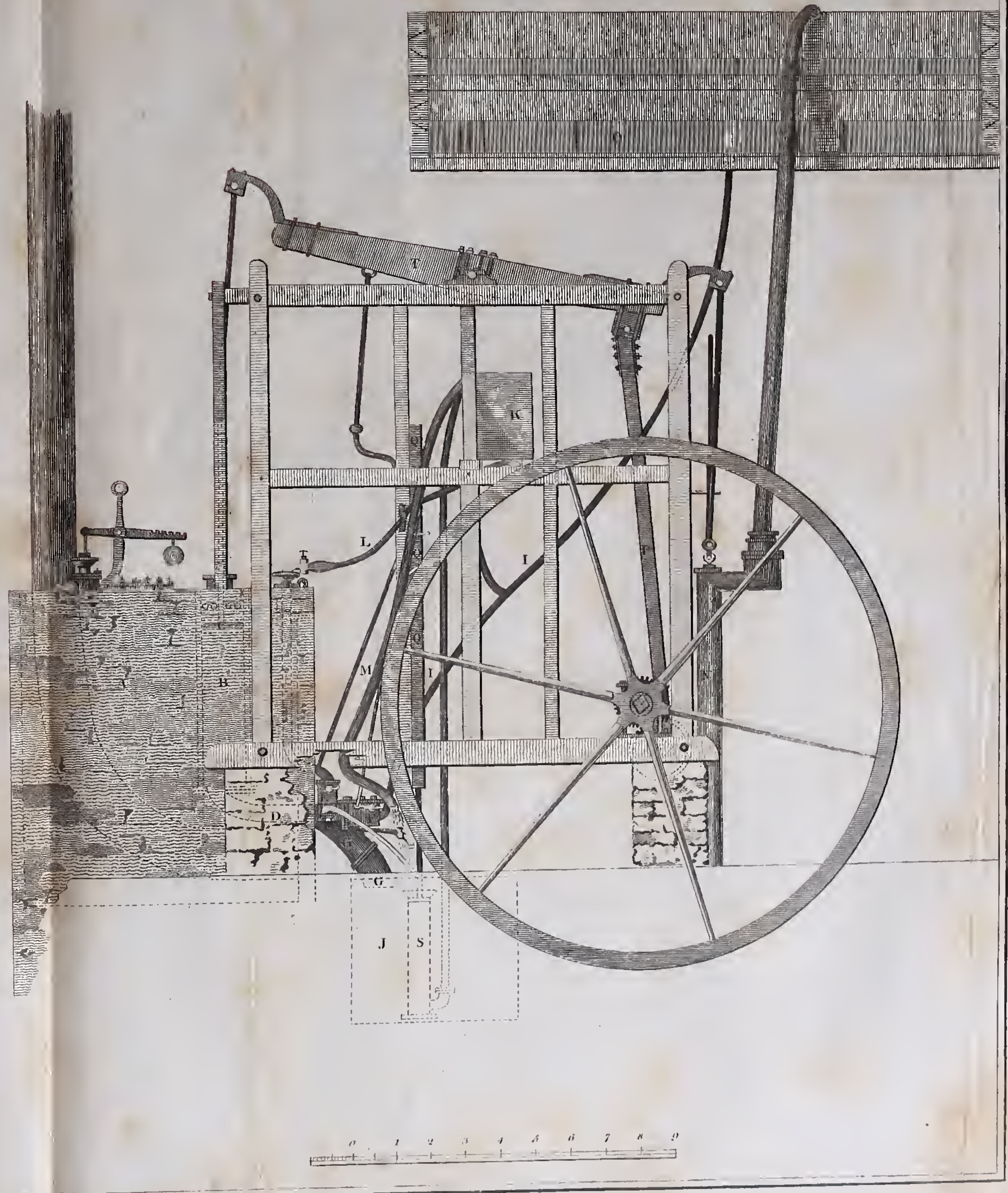


A	The Boiler.
B	Steam Pipe.
C	Man hole Door.
D	Loading Valve or Safety Do.
E	Feeding Pipe to the Boiler.
F	Fire Door.
G	Ash hole.
H	Cylinder.
I	Nozles Upper & Lower.
K	Plug frame & Irons to open Valves.
L	Beams that hold to Cylinder.
M	Exhaustion Pipe.
N	Injection Do.
O	Blowing Do.
P	The Barometer.
Q	Air Pump & Chains of Do.
R	Box of hot Water Pump.
S	Pipe & Cistern of Do.
T	Forcing Pump.
U	Timbers to steady the forcer of Do.
V	Jackhead Pump.
W	Air Vessel.
X	Upper Clack Door.
Z	Pipe to feed the Condenser Cistern.
B	Working Beam.
A	Timbers Supporting of Do.
C	Spring Beam.
D	Springs on Do.
E	Floor & Joists.
F	Ladder to Do.

Barlow sculp.

Mr. Walker's improved Steam Engine.

Pl. XXVIII.



Barlow sculp.

A SYSTEM
OF
FAMILIAR PHILOSOPHY:
IN
TWELVE LECTURES;

BEING THE COURSE USUALLY READ BY

MR. A. WALKER.

CONTAINING

THE ELEMENTS AND THE PRACTICAL USES TO BE DRAWN FROM THE
CHEMICAL PROPERTIES OF MATTER: THE PRINCIPLES AND
APPLICATION OF MECHANICS; OF HYDROSTATICS;
OF HYDRAULICS; OF PNEUMATICS; OF
MAGNETISM; OF ELECTRICITY;
OF OPTICS; AND OF
ASTRONOMY.

INCLUDING EVERY MATERIAL MODERN DISCOVERY AND
IMPROVEMENT TO THE PRESENT TIME.

*ILLUSTRATED BY FORTY-NINE COPPER-PLATES, NEATLY AND ACCURATELY
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1802.

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CONTENTS

OF THE SECOND VOLUME.

LECTURE VII.

LECTURE VIII.

LECTURE IX.

LECTURE X.

General View of Creation.—Ancient Opinions concerning it.—Reaſons why the Earth muſt be a Globe.—Why rather an oblate Spheroid.—How proved.—How its whole Surface becomes its general Top.—Day, Night, and the Seaſons, how produced.—How proved.—On the Celeſtial Globe.—Origin and Uſe of the Conſtellations.—Their Names.—Thoſe uſeful in Navigation.—Preceſſion of the Equinoxes.—Signs of the Zodiac.—Technical Aſtronomy.—Equation of Time.—Uſe of Time-keepers.—Reaſon of the Biſſextile or Leap-year.

LECTURE XI.

Nature of her Phaſes, Motion, and Eclipſes.—Of her Nodes, and their periodical Revolution.—Her Librations, what.—Horizontal and Harveſt Moon.—On the Cauſe of Tides, in the Air and Sea.—On Currents.

LECTURE XII.

Newtonian Doctrine reſpecting the Laws of Planetary Motion.—Character and Properties of the Planets, and their Moons.—Uſe of the Nautical Ephemeris.—On Altitude and Refraction.—On Comets, &c.

LECTURE VII.

ELECTRICITY.

THE hiſtory of philoſophy affords us nothing more early known than electricity, though it is generally conceived to be the lateſt diſcovery that has been made in the world of enquiry; for Theophraſtus expreſsly mentions it 300 years before the Chriſtian era; but all that was known of it, in that, and many ſucceeding ages, was little more than that amber, wax, glaſs, and ſuch ſubſtances, being rubbed, had the property of attracting feathers, ſtraws, and ſuch light bodies. It is not till within this laſt century, that we have been enabled to know that it is diffuſed, more or leſs, through every kind of matter on which we can make any experiments; and, that it is, perhaps, one of the moſt powerful and important agents in nature! What this wonderful matter is, has engaged the thoughts, and pens, of the firſt philoſophers of our times. It was called Electricity, becauſe it was firſt detected in amber, whoſe Greek name is ηλεκτρον, from ηλεκτωρ, *Sol*; a derivation that happily meets my ideas reſpecting the origin of this fluid; for I conceive it to be a child of the ſun; an equatorial emanation from that luminary; and the firſt ſource of light and fire. Not to multiply cauſes, but to make one cauſe account for as many effects as poſſible, I humbly conceive this ſubtil matter to be the genuine principle of light and fire: which, uniting with the fineſt particles of terreſtrial matter in the atmoſphere, becomes *light*; and chemically combining with the groſſer parts, *fire*. My reaſons for this hypotheſis are, their ſimilarity, in numberleſs inſtances, reſpecting *appearances, motion, power*, and other effects. As to *appearances*, impreſſions made on the optic nerve, by ſolar light, and electricity, are preciſely the ſame. The electric ſpark is commonly white like ſolar light; and when looked at, through a priſm, will be found to exhibit the ſeven primitive colours of red, orange, yellow, green, blue, indigo, and violet, like a ray of the ſun's light decompoſed in a dark room by a priſm. When difficulties ariſe in the tranſmiſſion of electricity, through dubious, or imperfect conductors, then none but red rays can ſtruggle through; and the ſpark is red: the ſun looks thus, when his rays are ſtopt by a fog, and none but the powerful red can force its way through it; ſo do diſtant lamps ſeen through a ſmoky atmoſphere in large cities. For if a round piece of ſmooth deal be covered, as *a b*, fig. 1, Plate XXIX. with tin foil, and three or four inches left bare, from *b* to *c*; and the part from *c* to *d* be covered; if the end *a* be held to an electrified conductor, a red ſpark will dart from *b* to *c*, over the uncovered ill-conducting wood. 2d. If a glaſs tube, of two inches diameter, and three feet long, have braſs caps at *a* and *b*, fig. 2, Plate XXIX. to make it air-tight; and by means of a ſcrew and a vavle, it can be fixed to an air-pump and be exhauſted of its air. If, when it is about half extinguiſhed, the end *b* be addreſſed to an electrified conductor, red flames will paſs through the tube: exhauſted a little more, and all the colours will paſs ſeparately and promiſcuouſly through the tube. But when nearly exhauſted to a vacuum, they will then go through altogether ſo mixed, as to appear white. Is not this ſimilar to the difficulties that ſolar light manifeſts in making its way through mediums of different reſiſting powers?

3d. Bodies much involved in light become, in general, coloured, volatile, and inflammable; and bodies the moſt coloured are the beſt conductors of fire: electricity impreſſes the colours of the rainbow on poliſhed metals, and makes even gold volatile. Are not theſe conformities favourable to the doctrine, that fire, light, and electricity, are but modifications of one and the ſame principle? 4th. When the eye has been ſome time ſhut up in the dark, and comes ſuddenly in the face of a clear ſun, if the eye be then cloſed, and kept ſo for ſome time, a ſtrong white impreſſion will continue on the optic nerve for ſeveral ſeconds; the ſpectrum will then turn violet; after ſome time blue, then green, and ſo on regularly in the order of the priſmatic colours. The firſt impreſſion is white, becauſe that is the natural colour of the ſun's light; or it may be called the reſult of a mixture of the ſeven primitive colours: the violet being the weakeſt, it becomes repelled from the optic nerve firſt, and producing an irritablity in its exit, induces a temporary ſenſation of that colour. The blue ſucceeds, &c. If the electrical battery, fig. 3, Plate XXIX. be charged, and the knob *a*, of the diſcharging rod, be firſt put to the knob *c* (which communicates with the inſide coating of all the jars), and the wire *d* (which communicates with their outſide coating) have one end in the water *m*; if then the knob *z* touch the water, a vivid ſtream of electrical light will paſs over the ſurface of the water from *z* to *d*, making (in the dark) the ſame impreſſion on the optic nerve as the ſun, which at firſt will be white, then violet, then blue, &c. Many other ſimilarities, in reſpect to *appearance*, might be brought forward; but we now proceed to compare the

Motion of light and electricity; both of which appear ſo inconceivably ſwift, as to ſeem incalculable! By the eclipſes of Jupiter's ſatellites, and the aberration of light from the fixed ſtars (ſee Optics), we can eſtimate the time in which light travels from the ſun to the earth. Not that I conceive the individual particles projected from the ſun reach the eye in eight minutes; I conceive all ſpace to be always filled with either active or latent electricity or light; which, in the latter caſe, is put into motion by *that* immediately projected from the ſun. For light and electricity being repulſive of themſelves, if the particle *a*, fig. 4, Plate XXIX. be juſt projected from the ſun *s*, it will repulſe the particle *b*; the particle *b* will repulſe *c*, &c. &c. and in eight minutes and twelve ſeconds the particle *i*, will ſtrike an eye on the earth. Electricity is likewiſe progreſſive in common experiments. Beccaria electrified one end of a wire of ſome hundred yards in length; he had ſmall pieces of leaf-gold placed near both its ends; when the excitation began, he ſaw the pieces of leaf-gold attracted at the electrified end, ſome inſtants ſooner than thoſe at the other end. Are not electrical effects, therefore, propagated through conducting ſubſtances, by putting their inherent and latent electricity into motion like the progreſſion of light? 2d. When a wire is heated red-hot by an electric battery, the red begins at the end next the poſitive conductor; proving that its motion is progreſſive. It is true, that electrical circuits have been made from the in to the out-ſide of the Leyden jars of ſeven, eight, and nine miles in length, through the crooked parts of the New River, the Thames, and alſo by a wire ſuſpended on a park wall of nine miles in circuit, which ſeemed to be ſo inſtantaneous, that no eſtimate could be made of the time it took up. I have electrified two regiments of ſoldiers, conſiſting of eighteen hundred men, who apparently all received the ſhock in the ſame inſtant. But a ſhock is like the diſcharge of a bullet through the air, which drives its particles into a maſs, and, therefore, we cannot judge of electric motion by its ſhocks, but by its progreſs through very long conducting ſubſtances. 3d. If feathers be ſtuck in each end of a long conductor, thoſe next the exciting cylinder will betray ſigns of electricity firſt; ſhewing that its motion through the conductor is progreſſive.

The ſimilitude of light and electricity, in reſpect to *power* or force, is particularly ſtriking. Light brought to a focus on opaque bodies by large lenſes or mirrors, produces the moſt intenſe heat (for what is light at the ſurface of a burning glaſs, is fire at its focus, if any ſubſtance containing latent fire be held in that focus). It will melt metals; vitrify ſtones; reduce ores and oxyds to metals; boil gold; fire ſhips, &c. Fire does the ſame; and ſo will electricity. If the battery, fig. 3, be charged, and a ſmall iron wire be tied to the hook *e*, and the other end to the knob *z*, of the diſcharging rod, and then, by the glaſs handle *f*, the knob *a* be brought to touch *c*, the diſcharge will paſs through the wire, and melt it. If the experiment be performed in the dark, the molten iron will fly about the room like red-hot bullets. If the battery be very large (ſuppoſe ſixty-four jars of about a gallon each, properly coated), the wire will loſe all metallic appearance, and be reduced to a calx, or oxyd, and fly about like little flakes of aſh-coloured cotton.

2d. Let pieces of leaf-gold be put at the tenth of an inch from one another, between two thin ſlips of window-glaſs, on the ivory table *a*, fig 5, Plate XXIX. and be held faſt to the table by the rods *c* and *b*, turning on the ſtiff joints *e* and *d*, and inſulated by the glaſs legs *g g*. If the battery, fig. 3, Plate XXIX. be charged and a wire or chain from the hook *e* join the rod *c*, fig. 5, Plate

XXIX. and the knob *z* of the diſcharging rod touch the rod *b*, at the ſame time that its other knob *a* touches knob *c* of the battery, the diſcharge will paſs between the glaſs ſlips, break them in its paſſage, melt or rather oxydate the gold-leaf, and enamel or incorporate it in the pieces of broken glaſs! If a ſmall weight be placed on the glaſs ſlips, the experiment will ſucceed better.

3d. By the electric ſhock, borax and glaſs have been melted, and metals revived from their calces or oxyds, as zinc and quickſilver; and it is ſhewn that the ſame things can be done by fire and by light. Are not theſe further proofs of their identity?

Of the other ſimilar *effects* of light and electricity numberleſs inſtances may be produced. Metals are calcined by light in the focus of a large burning lens, as fig. 6, Plate XXIX.: ſo are metals by large ſhocks of electricity; particularly quickſilver. If a crooked tube be half filled with quickſilver, and inverted in two glaſs veſſels filled with that metal, as *a* and *z*, fig. 6, Plate XXIX. and a wire communicating with the outſide coating of a large electric jar be hooked to the wire *c*; if then a communication be made (with the diſcharging rod) between the wire *d* and the inſide coating of the jar, a ſhock will paſs through the quickſilver and the ſpace *e*. When the ſhock has been ſeveral times repeated, the air in the ſpace *b e g* will be found conſiderably diminiſhed, and little red globules will appear on the ſurface of the quickſilver. If the ſhocks are continued, the pure part of the air will all diſappear, and become a part of the red calx or oxyd, agreeably to the manner of all calcinations.

2d. Vegetables thrive in light, and die in darkneſs: ſo inſulated beds of flowers, and all germination, frequently electrified, have had their growth accelerated; as well as the hatching of eggs. Both light and electricity change vegetable blue juices red; both produce flame; expand fluids; precipitate lime from lime water; and promote the growth of vegetables.

3d. Electric ſhocks, ſent through a ſword blade, excite the ſame order of priſmatic colours on the ſteel as is made on it by different degrees of heat; whether that heat is produced by culinary fire or light.

4th. Spirit of wine, ſmoke of a candle juſt put out, gunpowder, powder of colophony, reſin, &c. ignite with the ſmalleſt ſpark of electricity, even when conducted by a piece of ice; becauſe their latent fire is copious, and not fettered as culinary fire in general is by aqueous, ſaline, or terreſtrial particles, which make its diſengagement ſlow and inactive. Whereas electric fire drives into and excites the natural fire inherent in bodies.

5th. Canton's phoſphorus (made of calcined oyſter-ſhells), if hermetically ſealed in a glaſs, and expoſed to any coloured light, ſuch as may paſs through a ruby, a ſapphire, &c. may be ſeen to return or reflect the ſame light when inſtantly expoſed in the dark. So, when the ſame proſphorus is held near an electric exploſion, whatever is the colour of the exploſion, that colour will be ſeen emitting for ſeveral minutes in the dark from the phoſphorus. Hence letters, the planets, and many other devices painted with the white of an egg, and the pounded phoſphorus ſtrewed upon it, will continue luminous in the dark (after being held near an electric exploſion) for ſeveral minutes; and continue to have that effect for years, if kept very dry.

6th. Aſhes, coals, and other burnt bodies, revive to combuſtibility when expoſed to light, for uniting in the compoſition of vegetables they become again ſapid and inflammable. So if alkaline air (which is totally uninflammable) be incloſed in the tube *g e h*, fig. 6, Plate XXIX. over quickſilver, and electrical ſhocks be ſent through it for ſome time, the air will increaſe in bulk and become completely inflammable. Does not an inſulated combuſtible burn with greater vigor and brilliancy when electrified during the time of its combuſtion?

7th. Fire and light expand all bodies with which they unite, or come in contact with. So, if a tall glaſs jar be half filled with water, as fig. 8, Plate XXIX. and inverted in a veſſel, having the wire and knob *c* ſtanding in it; and then another knob and wire acting through the collar of leathers *d* be placed about an inch from the other knob, an exploſion from a large jar, and darting from *z* to *c*, will ſo ſwell the air as to depreſs the water in the jar.

It has been ſaid that electricity cannot be excited by the rubbing of two conducting ſubſtances together, nor by the friction of two non-conducting ſubſtances; this is not true; for, if two pieces of broken china be rubbed gently together, one piece will be in a poſitive, and the other in a negative ſtate; as may be proved by holding inſulated ſmall flaxen threads near them, as fig 7, Plate XXIX. *a b* being glaſs. But if the edges of the pieces of china be ſtruck briſkly together, they will produce ſparks of fire, but no electricity: for if the threads are held near them, no ſigns of electricity will appear. 2d. Two glaſs tubes rubbed briſkly together produce a vivid purple light in the dark, and a ſtrong phoſphoric ſmell; but no attraction or repulſion, as may be proved by the above threads *: but if two pieces of plate-glaſs be warmed and gently rubbed together, the one will be found in a condenſed ſtate, the other in a rarefied ſtate, by the above teſt. 3d. Air and glaſs are both non-conductors; yet if warmed glaſs be blown on by a pair of bellows it will betray ſigns of electricity, ſo will amber. May not gentle friction, therefore, exhibit fire in the pure character of electricity? and when more violence is uſed, call it forth (mixt with terreſtrial matter) as common fire?

Theſe analogies, I hope, prove the identity of light, fire, and electricity; and if light and fire have been proved in another lecture to be derived from the Sun, I truſt we may alſo conſider him as the parent of electricity. Yet ſtill there are great differences between the action of fire and electricity. Ordinary fire or light will not give the electric ſhock, nor produce lightning; neither will ordinary air diſcharge a bullet till it is condenſed; yet ſtill it is air.

Why is there more thunder and lightning in ſummer than in winter? in hot than in cold climates? Is it not becauſe the ſun's

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* Yet friction univerſally produces electricity: two non-electrics rubbed together have their electricity diſturbed, but inſtantly reſtored; and two electrics rubbed together betray no ſigns for the ſame reaſon: ſo when effects are not ſenſible, it is only becauſe electricity is loſt as ſoon as produced. My coat grows more duſty by long bruſhing; for electricity is excited by the friction of the bruſh, and the motes and duſt of the air are attracted to it.

rays are more direct upon us at that ſeaſon, and that a greater quantity of electricity falls on that part of the earth and its atmoſphere? May not that abundance ſometimes ſo ſuperſaturate the upper regions of the air (which from its rarity is a conductor, and of courſe a receiver of electricity), that it ſhall make violent efforts to get through the non-conducting lower regions of the atmoſphere, and produce thunder and lightning? Are not thoſe concentrations of electricity called thunder-bolts favourable to this opinion? For, that accumulated lightning does often aſſume the appearance of a ball of fire is beyond all doubt; and ſuch have even been produced by artificial electricity. I conceive ſolar light to be in a more elementary ſtate in the character of the electric fluid, than it is in either ordinary fire or light; for in our experiments upon both we always find them entangled with terreſtrial matter: could we refine them from that matter, I preſume to think the reſult would be electricity. May not this etherial matter be pure electricity coming from the ſun, but mixt and ſo far contaminated in travelling through our atmoſphere, that *in the air it ſhall only be light, and in the earth fire?* That this fire ſhall be culinary when called forth from the earth, by ordinary *combuſtion,* and electric when called forth by *friction?* The atmoſphere is generally in a condenſed ſtate, except when it is in a ſtate of diſeaſe by thunder and lightning; it is then poſitive and negative, or in a ſtate of alternate condenſation and rarefication, by ſwift gradation, indicative of the perturbed ſtate of the air, which cannot conduct the lightning ſwift enough into the earth; or, the earth's attraction, for it cannot be ſatisfied without a negative exertion in its favour, to help it through the air. Do we not often ſee condenſed lightning fall from the atmoſphere like a ball, and roll along the dry earth before it can make its way into it? and do we not often ſee it, in the character of a meteor, fly obliquely the length of a nation before it finds the ſea, or ground ſufficiently moiſt for its admittance? and may not comets themſelves be a condenſation of oppoſing light, from different ſuns, concentrated by oppoſition, and impelled into the ſtream of the moſt powerful light? As calculation has failed in regard to thoſe wonderful bodies, a conjecture I hope may be pardoned.

SECTION II.

On Electrical Machines.

HAVING thus endeavoured to eſtabliſh what I conceive Electricity to be, I muſt now try to explain the beſt modes of its excitation, and making thoſe experiments already mentioned. An electrical machine is now ſo common, that I ſhall only mention the two forms I think the beſt. A cylinder of well annealed glaſs, about eighteen inches long in the belly, and fourteen diameter, is a good ſize. The caps ſhould be of hard wood, as round and ſmooth as poſſible, and of a piece with centres on which the cylinder turns: to one of theſe centres the handle *a* ſhould be fixed, fig 9, Plate XXIX. The two conductors, *b* and *c*, are of copper or tin, very ſmooth, round, and without points or edges, of about eighteen inches long, and eight inches diameter. To the negative conductor *b*, muſt be fixed an elaſtic cuſhion of red leather, ſtuffed evenly with curled hair, of about ten inches long, and fixed ſo as to lie flat to and fit the cylinder: on its under ſide muſt be ſewed a piece of the above leather ten inches wide, and five inches long; and at the ſame place a piece of black Perſian ſilk ten inches wide, and ſixteen inches long, that will reach over the cylinder, as *d*:

to the prime conductor, *c*, muſt be attached a row of eight points, each about the length of common pins, whoſe points muſt be as near the glaſs cylinder as poſſible, without touching: both ends of the cylinder, as well as the two conductors, muſt be ſupported on ſolid glaſs pillars. The pillar *g* ſhould be faſtened on a piece of board that could ſlide in a groove, and be fixed by a wooden ſcrew to the board that ſupports the whole machine: this is to preſs the cuſhion more or leſs to the cylinder. On the part of the ſilk that touches the cylinder, under the cuſhion, ſhould be ſpread a little amalgam*, and the machine is then ready for experiments.

Another machine, of greater power, is made of a round plate of thick looking-glaſs, fig. 9, No. 2, Plate XXIX. This plate turns on an axis *a*, ſupported by the mahogany frame *c c c*, by the handle *g*. The rubbers are of red leather ſtuffed with curled hair, and nailed to thin ſlips of wood, *d d*, one on each ſide of the glaſs, and made to preſs the glaſs very cloſe by the ſcrews *x x*. To theſe rubbers are attached oil'd ſilk curtains, *z z*, on both ſides of the glaſs. The conductor, *w w w*, is of braſs, and fixed to the frame *c c c*, by the glaſs ſupporter *q*, which inſulates the conductor *w*, and terminates in the two knobs *s s*; into theſe knobs are ſcrewed ſmall cylinders of braſs, with a number of points that nearly touch the glaſs, and receive the electric matter from it: they cannot be ſeen in the drawing, being behind the curtains. For exciting poſitive electricity in all kinds of weather, and ſituations, this

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* Melted zinc poured on an equal weight of quickſilver, and ſtirred together, makes a very good amalgam. A better is ſaid to be by melting two ounces of tin, and one ounce of zinc, and pouring theſe on three ounces of quickſilver in a wooden box well chalked within; being ſtirred, they unite into a hard maſs, which muſt be well pounded and ſifted through cambric, and then mixt with as much hog's lard as will make it ſpread.

is the moſt powerful and convenient machine that has yet been invented.

Before we begin to uſe the machine, it may be neceſſary to lay down a few electrical axioms. 1ſt. All natural bodies are divided into two claſſes, *electrics* and *conductors*. *Electric* ſubſtances, ſuch as glaſs, air, ſilk, &c. will not tranſmit electricity, but with difficulty, and ſhort diſtances: *conductors*, ſuch as metals, water, &c. do tranſmit it. 2d. Conducting and non-conducting ſubſtances rubbed together, appear to be both electrified, but poſſeſſed of very different quantities; as when glaſs is rubbed with a piece of leather, the glaſs will be found in a poſitive, plus, or condenſed ſtate; the leather in the negative, minus, or rarefied ſtate. 3d. By this we are not to underſtand that there are two electricities, though called by ſo many oppoſite names. Electricity and lightning *are one fluid*; probably, as before obſerved, an emanation from the ſun's atmoſphere; and by poſitive and negative is only meant *more* or *leſs* of one and the ſame fluid. 4th. Bodies poſſeſſed of the ſame electricity, whether poſitive or negative, repel each other: poſſeſſed of different quantities, they attract each other. 5th. When bodies too heavy to be drawn by electrical attraction come near an electrified body, they inſtantly become poſſeſſed of an electricity contrary to that of the electrified body; i. e. the electrified body diſturbs, repels, or drives away the natural latent electricity of the body towards the end fartheſt from the excited conductor. 6th. When electricity enters a point, it appears a ſtar in the dark: when it iſſues from a point, it is like a bruſh. In the laſt caſe it often flames from the rubber of the machine, into the air, when not carried off faſt enough by the points of the conductor. 7th. An electric atmoſphere not only repels another electric atmoſphere, but it will alſo repel the electric matter in the ſubſtance of any body it approaches; and, without mixing with it, force it to a further part of that body.

If a chain be hung to the negative conductor *b*, fig. 9, Plate XXIX. reaching to a moiſt floor, wall, or any conducting matter communicating with the earth, and the cylinder be turned, ſparks may be taken by the knuckle, or any piece of metal, from the prime conductor *c*, at two, three, or more inches diſtance.

That electricity after penetrating through the atmoſphere, and approaching the earth, has its affinities like other matter, and becomes a latent principle in bodies till called into activity by frictions or heat, is more than probable, from the readineſs with which ſome bodies part with it, and the tenacity with which others retain it. Hence the earth has been conſidered as the grand reſervoir of electricity; and, therefore, that a metallic communication between the rubber and the earth was neceſſary as a road for the fluid to the machine. The friction at the rubber draws from the earth a portion of its natural electricity, which forms an atmoſphere round the glaſs cylinder, and is ſupplied by the communicating chain hung to the negative conductor *b*. This atmoſphere is attracted by the metallic points of the prime conductor *c*, and conveyed by them from the cylinder to the ſurface of that conductor, which becomes poſitively electrified; i. e. poſſeſſed of more electric fluid than it poſſeſſes naturally. This ſuper-quantity will endeavour to get back to the earth, or equalize itſelf with any conducting body near it; and hence it darts into my knuckle, or into any metallic ſubſtance I hold in my hand, making the conducting moiſture of my body a path-way back to the ground, to which it has a ſtrong affinity.

2d. I now take the chain from the conductor *b*, and hang it on the conductor *c*, which will then give no ſparks; but when I addreſs my knuckle towards *b*, ſparks will again *ſeem* to ſtrike me; but, in reality, they now dart from my hand to the negative conductor: I then convey the fluid from my feet to my hand, as before I conveyed it from my hand to my feet, as will be proved hereafter.

3d. I now take the chain away, and the whole machine is then inſulated from the earth, as all its parts are ſuſtained on non-conducting glaſs pillars. I alſo ſtick into the conductor *b* the wire *z*, bringing its knob within three or four inches of that in the conductor *c*. On turning the cylinder, ſtrong ſparks dart from the knob *q* to the knob *p*. How is this, when the whole apparatus is cut off from any communication with the earth, the grand reſervoir of electricity? The conductors contain a natural quantity; but by the excitation, the conductor and rubber *b* becomes minus, or robbed of a portion of its natural quantity; while the conductor *c* receiving it, becomes plus, poſitive, or poſſeſſed of more than its natural quantity: hence the poſitive knob, *q*, delivers back to the negative knob, *p*, its ſuper-quantity, in vivid ſparks. This ſhews that bodies do not loſe their natural electricity by being inſulated from the earth. For where this natural quantity remains undiſturbed, no electric ſigns appear; but when it is diſturbed, as in the above experiments, then one part becomes condenſed, another rarefied; it is in a ſtate of redundancy in one place, and in a ſtate of deficiency in another; but each makes an effort to meet the other, to reſtore an equilibrium, and then all is at peace.

4th. If the wire $z\ p$ be ſtuck in its conductor, ſo that its knob may be about an inch from the ground; and a ſimilar wire and knob be ſtuck in the conductor *c*, ſo that its knob may alſo be about an inch from the ground;—ſo ſoon as the excitation begins, electricity will jump from the earth to the negative knob, and at the ſame inſtant from the poſitive knob into the earth; one drawing it from the earth, the other delivering it back to it.

SECTION III.

On Points.

THAT points, attached to conductors, both receive and deliver the electric fluid more eaſily than flat or round bodies, is evident from this experiment:—Hold the knob of a braſs rod at ſuch a diſtance from the prime conductor, that ſparks may fly to it; then preſent the point of a needle to the conductor at twice the diſtance of the knob, and the ſparks will ceaſe; remove the needle, and the ſparks will be ſeen again; preſent the needle, and the ſparks diſappear again: certainly ſhewing that the needle draws off the fluid in a ſtream ſilently; which may be ſeen like a ſtar on the point of the needle, when the excitation is performed in the dark.

2d. Fix a wire, with a ſharp point, into the end of the prime conductor, and hold a knob, or your hand, near it; no ſparks will enſue; but a cold blaſt will iſſue from the point that will turn light mills, or wheels, as fig. 10, Plate XXIX. which is a round piece of cork, with the feather ends of quills ſtuck in it; a ſmall needle is fixed in the centre of the cork, ſo that the whole can be ſuſpended by the magnet *m*. On the cylinder being turned, an aura will iſſue from the pointed wire *w*, that will blow the wheel round with great ſwiftneſs.

3d. If another point be held half an inch from the point juſt mentioned, a beautiful ſtream of fire will be ſeen running from the electrified point into the other, producing a crackling kind of noiſe.

4th. Let the needle *n*, fig. 11, Plate XXIX. be ſtuck perpendicularly into the prime conductor, with the four wire arms ſuſpended on its point: if the ends of theſe arms be filed into points, and turned at right angles horizontally, and all in the ſame direction, when the machine is turned, the arms will whirl round, and exhibit a ring of fire in the dark. This is occaſioned by the reſiſtance the air gives to the electric aura, ſpouting out at the four points.

5th. If one piece of wire be bent as the two were in the laſt experiment, and ſuſpended on a point, inſulated by the glaſs ſupport *a*, fig. 12, Plate XXIX. and from one of the arms a ſmall glaſs clapper be hung by a ſilken thread, *c*, and the glaſs ſupport be ſtuck in the centre of eight ſurrounding bells; a chain being hung from the prime conductor, almoſt to touch this apparatus at *s*: when the machine is put in motion, the wire will circulate, and ring the eight bells. This pleaſing effect depends on the ſame cauſe as the laſt. The chain being electrified, communicates electricity to the ſuſpended wire; and as that is ſupported by glaſs, and the clapper by ſilk (both electrics, or non-conductors), the fluid has no-where to eſcape, but from the points of the ſuſpended wire; where its aura meets a ſufficient reaction from the air to puſh it round.

6th. The electrical orrery is another device dependent on the aura that ſtreams from electrified points. On a wire bent, pointed and balanced as the laſt, let a ſmall globe of glaſs be fixed, over its centre, as *a*, fig. 13, Plate XXIX. to repreſent the ſun: into one end of this wire let there be fixed a ſmall well-pointed wire, half an inch long, and ſtanding perpendicularly. On this wire the earth and moon's wire is ſuſpended, as *w* in the figure: this wire is alſo bent like the letter *z*, having a round pith ball fixed on its centre to repreſent the earth; and a ſmaller, fixed on one of the angles, to repreſent the moon; the whole ſuſtained by the glaſs *b*. When the chain *c* is fixed to the conductor, and the machine is excited, the ſun will turn on its axis; the earth will have its diurnal and annual revolutions; and the moon will accompany the earth, making twelve revolutions round it, while the earth makes one round the ſun.

7th. That this power is ſo conſiderable as to counteract the power of gravity in light bodies, is curiouſly exemplified in fig. 14, Plate XXIX.: a wire, having its ends pointed, and bent in contrary directions, like the laſt, is fixed to an axis of the ſame kind of wire, perpendicular to the direction of the points; this axis laid on the two parallel inclining wires *c* and *d*, will roll down them by its own gravity: but when it is nearly arrived at the bottom, if the machine be put in motion, the axis will return, rolling up the inclined plane. N.B. The ſupports *a* and *b* muſt be of ſolid glaſs.

More has been ſaid on this part of electricity than may be thought neceſſary; but, connected as the ſubject is with thoſe pointed rods uſed for the preſervation of our dwellings from the effects of lightning, they have been conſidered as properly introductory.

From the eaſe with which electricity enters into, and iſſues from, points, together with its ſtrong affinity to metals, it was a natural ſuggeſtion, that long metallic rods, terminating in one or more points, would draw lightning from the atmoſphere ſilently, or in a progreſſive ſtream, and thereby prevent the miſchief it often does when obliged to come in a body upon houſes, trees, or ſubſtances that are bad conductors. For where conducting nails, iron cramps, bolts, locks, tongs, &c. are at a conſiderable diſtance, lightning ſeems to accumulate its force in proportion to the difficulties it has to encounter, or to the length of the non-conducting matters that ſeparate one conducting body from another. Theſe are the ſituations, where buildings, &c. ſuffer from lightning. Accordingly, to prevent this, long rods of iron, about three fourths of an inch diameter, are ſcrewed to the ends of one another, ſo as to reach about five feet above the top of the higheſt chimney of the houſe, and to go, as ſtraight as the building will admit, down to the ground, into which its other end ought to penetrate five feet, ſo as to be always in conducting moiſture. Leaden ſpouts, gutters, the ſheet-lead covers on the hips of houſes, are all good conductors; and if iron rods be fixed againſt the chimneys, and join the ſpouts and gutters, ſo that there be an uninterrupted continuation of lead or other metal into the ground, theſe are as ſecure conductors as the iron rods. N.B One conductor ſeems only to ſecure a building to the diſtance of about ten yards around it; for at fifteen yards from a conductor a building has been ſtruck.

In what manner points operate upon lightning, or electricity, has been matter of much ingenious conjecture. When a ſpark is taken from a large conductor, it is larger and more intenſe than when taken from a ſmaller conductor, diminiſhing in ſize and brightneſs, but increaſing in length, as the conductor diminiſhes; ſo that when the conductor ends in a point, the ſpark becomes ininviſible, but of ſuch a length, that it is felt on the face like a cobweb at ſeveral feet diſtance. Suppoſe the electric atmoſphere round the conductor *a*, fig. 1, Plate XXX. to be repreſented by the ſpotted lines, then may the aura be felt at *c* on the hand, and on the face (as above) at four or five inches diſtance; being thus repulſed into the air, or to conducting ſubſtances near it. The attraction which the conductor has upon the electric matter on its ſurface being, therefore, *as* that ſurface, and a point having no ſurface, the electricity can more eaſily enter into, or eſcape from, a point, than from a flatter body. When a ſhaggy feather is laid on the prime conductor, and the machine put in motion, the fibres of the feather will dart out radiantly, and preſently it will take its flight from the conductor. The feather (though a very imperfect conductor) conſiſts of ſo many fibres and points, that the electric matter can eaſily iſſue through them; and by electrical repulſion ſpread out the fibres: but when the feather becomes filled with electricity, a repulſion between it and the prime conductor takes place, and it is thrown off to any neighbouring body that will take from it its ſuperfluous electricity: it then becomes ſuſceptible of being attracted to the prime conductor again, and becomes a carrier of electricity from it to the neighbouring bodies. But if while the feather ſtands erect on the prime conductor, the point of a needle be held at a foot diſtance from it, the feather will inſtantly cling to the conductor, as if afraid of the point. The point being of metal, is a better conductor than the fibres of the feather. Now if a feather, *a*, be ſtuck in the end of the prime conductor, fig. 2, Plate XXX.

and electrified, the fibres will become radiant, and have a repulſion in the direction of the arrows *c z q:* but if a point, *d*, be preſented to it, a ſtream of electricity will iſſue from the feather to the point, and, by crowding to it, become condenſed at *d:* that condenſation will increaſe the repulſion of the point, and particularly in the contrary direction of the ſtream *; ſo that the repulſive power *d s*, being greater than the diffuſed repulſion *a*, *z*, will drive the feather back, and make it cling to the conductor as if afraid of the point.

Perhaps there may be ſomething in the poliſh, and diſpoſition of the pores, in a point, that is more friendly to the receipt and delivery of electricity than in flatter bodies; for we find that it makes greater efforts, and ſeems to have more difficulty in making its way into large knobs than into ſmaller; ſo that a point being the leaſt poſſible ſurface, electricity muſt needs enter it with the leaſt difficulty, if made of conducting matter. Hence as the clouds may be conſidered as the outſide coating of a Leyden jar, and the earth as the inſide coating; and the non-conducting air between them as the glaſs of the jar; the fig. 3, Plate XXX. may aſſiſt the young electrician to conceive how a pointed conductor draws lightning from the clouds.

On the Attraction and Repellency of Electricity.

Electricity attracts all kinds of bodies, and is repulſive of itſelf. A feather hung by a ſilken thread within a foot of an electrified conductor, will be attracted to it, and inſtantly repelled. The electric atmoſphere which adheres to the conductor, attracts the feather;

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* When it is conſidered that there are a great number of bad conducting points from the feather, and but one receiving point of metal, the condenſation at that point muſt be ſo great, that the *reaction* will overpower the emanation from the feathers.

a portion of that atmoſphere immediately adheres to, and ſurrounds, the feather: now as the electric fluid is repulſive of itſelf, and the feather has acquired an atmoſphere, as well as the conductor, the two atmoſpheres repel each other, as the arrows in fig 4, Plate XXX.

2d. Thus, if four ſmall bells be ſuſpended by wires from two braſs wire arms, *d* and *o*, fig. 5. Plate XXX. and on theſe arms be hung four clappers by ſilken threads, at a proper diſtance from the inſulated central bell *a* (the ſupport *c* being ſolid glaſs); if then a chain, *g*, form a communication between the wires and the prime conductor, and the machine be put in motion, the clappers will begin to move ſwiftly between the four electrified bells and the bell *a*, ringing the whole five. The four outſide bells, communicating with the prime conductor, will be in a poſitive ſtate, while the bell *a* will be in its natural ſtate, becauſe its ſupport *e* is of metal, and communicates with the earth, by means of the table, the floor, and walls of the room. The clapper *z* being attracted to the bell *q*, receives an atmoſphere of electricity, by which it becomes repelled from *q*, and attracted by *a* where it delivers its atmoſphere, and becomes liable to be attracted again: hence the clappers are the carriers of electricity from the electrified bells to the bell *a*, which keeps altogether in its natural ſtate, as the ſtand *e* conveys away the fluid as faſt as the clappers deliver it.

3d. Cut a few ſmall figures in thin paper, as fig. 6, Plate XXX. and place them on the ſmall metallic table *c*: let a thin plate of braſs, as *d*, hang from the prime conductor juſt above the figures. When the machine is excited, the figures will get up and dance in a whimſical manner. The cauſe of which muſt appear, from what has been ſaid, to be the attraction of the electrified plate *d*, to which the figures jump, and are inſtantly repelled back to the table *c*; ſo that they become the piece-meal carriers of the electric matter from *d* to *c*.

4th. While the machine is in motion, put the knob of the prime conductor into the glaſs receiver *a*, fig 7, Plate XXX. making the knob touch all the interior ſurface of the glaſs; then ſuddenly place it over a few ſmall pith balls on the above table, when inſtantly the balls will begin to fly about the glaſs, and with a laughable commotion continue to do ſo for ſeveral minutes. When they ceaſe, if a hand touch the glaſs, they begin to fly about again, and ſo on for ſeveral times. We ſhall ſee by the Leyden vial that the receiver was charged with condenſed electricity on its inſide, and negative on its outſide; and in that ſtate was placed over the pith balls: the balls were attracted to the abundant ſide, and inſtantly repelled down to the table, as in the foregoing experiments, carrying off by degrees the poſitive quantity to ſupply the negative ſide. But when the equilibrium is nearly reſtored, the electricity becomes too weak to affect the balls, and they ceaſe to jump: if then a hand or piece of metal touch the glaſs, they begin again; becauſe a better conducting road is made between the in and out-ſide of the glaſs, ſo that the remaining electricity can make an exertion by means of the balls, the table, and the perſon who touches the glaſs, to make its way to the outſide.

SECTION IV.

On the Leyden Vial.

THIS aſtoniſhing vial derives its name from the place where its effects were firſt diſcovered. It is a glaſs jar or bottle, coated both within and without, to the diſtance of two inches of its brim, with tin foil, fixed on with paſte or gum-water. It has a thin cover of baked wood, through the centre of which is ſtuck a ſtrong wire, terminating in a number of ſmaller, that touch the inſide coating of the jar; the top of the ſtrong wire terminates in a braſs knob, *a*, with a hole on its top to hold an electrometer*, fig. 8, Plate XXX. When the knob *a* communicates with the prime conductor, and the machine is excited, the ball *c* of the electrometer will ſeparate from the ball *a*; and when its rod ſtands horizontally, it indicates that the jar is fully charged. If then one knob of the diſcharging rod touch the outſide coating, and the other approach the knob *a*, when they come within an inch of each other, an exploſion will take place between them.

The cauſe of this ſtriking phænomenon has been variouſly accounted for; but as I have made it a rule through this work not to incumber it with divers opinions, or take up the reader's time with their inveſtigation, I proceed to adopt that explanation which ſeems to me moſt agreeable to nature, analogy, and phænomena

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* An electrometer is an inſtrument for meaſuring the charge of a jar or battery; founded on the principle of electrical repulſion, as explained in the laſt ſection. It conſiſts of a ſemi-circle fixed as fig. 8, Plate XXX. and graduated into two quadrants. From the centre of the ſemi-circle is ſupended on braſs pivots a ſmall rod of wood, with a pith ball at its extremity.

founded on the obſervation and experience of above forty years. When a Leyden bottle is hung to the prime conductor, by a wire touching its inſide coating, and its outſide coating touches only the air, it will not receive a charge. The air, as well as glaſs, has ſo ſtrong an affinity to electricity, that it parts with it with great difficulty; and being in general ſaturated with it, receives it with equal difficulty. Hence when electricity is excited, it adheres to the ſurface of the prime conductor for ſome time before the air (or perhaps the moiſture in the air) can carry it off; and the interior ſurface of the bottle being in the ſame ſtate, will have its electricity carried off alſo: when the diſcharging rod, therefore, makes the communication between its in and out-ſide coatings, little or no electricity appears. But when the outſide coating touches any conducting ſubſtances that communicate with the earth, the rubber, or negative conductor; and the inſide coating communicates with the prime conductor; the jar, or bottle, will charge and diſcharge as above. In the firſt place we muſt conſider the electricity *inherent* in the glaſs as increaſed and diſturbed by that thrown on its inner ſurface by the machine: accumulated on that ſurface, a proportional quantity is forced through the glaſs to its other ſurface into the conducting ſubſtances that touch the outward coating, as indicated by the arrows, fig. 8, Plate XXX.; hence the inſide is ſaid to be plus, and the outſide minus; or poſitive and negative: or, to be more explicit, the inſide ſurface is in a ſtate of ſuperabundance, and the outſide ſurface is in a ſtate of want. When, therefore, a metallic communication is made between the in and out-ſide coatings, the ſuperabundant electricity (ſo induced upon the inner ſurface) makes an effort to reſtore the equilibrium of the two ſides, by darting from *a*, the poſitive knob to *e*, the knob that communicates with the negative ſide of the jar; this ſtream, joining the propelled electricity, repreſented by the darts, fig. 8, Plate XXX. both return to the outſide, and the equilibrium is reſtored with a flaſh and exploſion at *a c*. The tin-foil coating only diſtributes the electricity equally over the ſurface of the glaſs; for glaſs may be charged without any coating, as in fig. 9, Plate XXX. where a blunt-ended wire, *a*, hangs from the conductor *d*, within half an inch of the plate of window-glaſs *g*: when the machine is excited, a bruſh of electrical light will fall from the wire *a* on the glaſs for a few ſeconds, and then ceaſe; but if a blunt-ended wire, *n*, be held oppoſite the wire *a*, about half an inch from the under ſurface of the glaſs, the bruſh will re-appear, as well as a ſtar on the blunt end of the wire *n*. After ſome time theſe effects will ceaſe: but if the glaſs be moved ſo that the wires *a* and *n* may be oppoſite on various parts of its ſurface, the whole of the upper ſurface will be charged poſitively, and the under ſurface negatively, and a metallic communication between the two ſides will produce a flaſh and exploſion, the ſame as a coated jar.

2d. If a looſe coating, or patch, of tin-foil be laid on the glaſs when ſuſtained by a hand underneath, and the patch be electrified, and then ſhook off the glaſs, the other hand, applied to the place where it lay, will receive the electrical ſhock.

The *bruſh* indicates the delivery of electricity; the ſtar its reception: ſo that it is ocular, that the upper ſurface of the glaſs, in the firſt experiment, had the electricity forced or induced upon it, while an equal quantity was propelled from the other ſurface into the wire *n*. If the glaſs, ſo charged, be removed from the machine, and a crooked wire, with its ſharp pointed ends, be held in the poſition *o*, ſo that each point may be half an inch from the upper and under ſurface of the glaſs, the electricity will return from the under to the upper ſide, making a bruſh below, and a ſtar above; thus the equilibrium is reſtored.

Glaſs and air being non-conductors, it is difficult to force electricity out of glaſs into air, by any accumulation: hence the neceſſity of conducting ſubſtances being joined to the oppoſite ſide of the glaſs, or jar, to that on which the electricity is induced. Suppoſe *a c* one ſide of a plate of glaſs, and *d e* the other, fig. 10, Plate XXX., and that the natural electricity in the glaſs, and in the air on each ſide of it, was repreſented by darts, both being in a quiet ſtate.—But now we will ſuppoſe this quiet ſtate to be diſturbed by the near approach of the electrified conductor D, fig. 14, Plate XXX. from which electricity will be repelled in the direction of the darts *r s*. This will diſturb and repel the electricity within the glaſs plate *n o z q* to the pointed metallic receiver E. If now the glaſs plate be removed, the ſide *n o* will be found in a condenſed ſtate, and the ſide *z q* in a ſtate of want; and a metallic communication between the two ſides will produce the electric flaſh and report. This I hope may be conceived as a picture of what paſſes in the glaſs of the Leyden bottle, when expoſed to accumulated or condenſed electricity; and alſo the theory of charging plates of air, of wax, of cryſtal, of reſins, and all other electric bodies.

That plates of air can be charged like plates, or jars, of glaſs, is evident from the experiment, fig. 11, Plate XXX.: *a* is a circular ſmooth board, of two feet diameter, ſuſpended from the prime conductor by the chain *g*; it is covered with tin-foil, and hangs a few inches above a ſimilar board covered alſo with tin-foil, which communicates by conducting ſubſtances with the earth. If the machine be put in motion, the chain *g* and plate *a* will be poſitively electrified, and repel the electricity of the plate of air between the boards *a* and *e* into the board *e*, and the ſubſtances in contact with it; *a*, therefore, repreſents the inward coating of the jar, fig. 11, Plate XXX. and the board *e* the outward coating: if one knob of the diſcharging rod touch the board *e*, and the other the board *a*, the flaſh and report will take place as with the Leyden jar; or if one hand touch the board *e*, and the other the board *a*, the electric ſhock will be felt; proving that the plate of *air* between *a* and *e* can be charged the ſame as glaſs.

N.B. The edges of the boards ſhould be made round and ſmooth, for edges and points diſperſe electricity: and if the upper board were ſuſpended from the ceiling of the room by ſilken cords, ſo much the better.

2d. Two rulers, like two black-lead pencils, are covered with tin-foil, and ſuſtained on the glaſs pillars *a* and *b*, fig. 12, Plate XXX. From the end of each ruler hang two pith balls by fine flaxen threads. When theſe rulers touch each other, as in the figure, and a clean warm glaſs tube, *z*, be rubbed with a dry ſilk handkerchief, and held in the poſition as in the figure, and ſo to have a plate of air between it and the end of the ruler *a*, the natural electricity contained in the two rulers will be repelled towards their extremity, as denoted by the darts. If, while their electricity is in this diſturbed ſtate, the pillar *b* be removed from *a*, its ruler and balls will be found in a poſitive ſtate, while thoſe of *a* will be found negative, or in a ſtate of want: this may be proved by bringing the excited tube *z* within a few inches of the balls ſuſtained by the pillar *b*, which balls will be repelled; but if the tube be brought near the balls ſuſtained by *a*, they will be attracted. It has before been obſerved, that electricity repels itſelf; and attracts, or is attracted, by all other bodies. Hence the balls ſupported by *b*, being in a poſitive ſtate, repel each other, and thoſe ſupported by *a* ſeem alſo repelled; this ariſes from being deprived of their natural quantity, and ſoliciting a ſupply from the ſurrounding bodies, towards which they have a natural attraction. If the experiment be made with an excited ſtick of ſealing-wax, the ſame appearances take place, though with contrary electricities; for now the natural electricity of the two rulers is attracted *towards* the end over which the wax is held, to ſupply the wax's deficiency, and that end will be found poſitive, while the other end is negative. For the earth, the air, water, and every ſubſtance contained in each, will generally be found naturally in a poſitive ſtate; and that matter, diſturbed by excited glaſs or wax, exhibit its phenomena from the before-mentioned principles, viz. *That excited glaſs acquires electricity from the ſubſtances with which it is rubbed; and excited wax loſes a portion of its natural quantity by delivering it to the rubber.*

3d. Fig. 13, Plate XXX. is a ſmall coated jar, ſtanding in a cup of tin, and ſupported by the ſolid glaſs foot *s*. From the knob communicating with the inſide coating of the jar, there projects a wire, ſuſtaining, by fine flaxen threads, the pith balls *z*; and from the tin cup, a wire alſo ſuſtains a pair of pith balls. I take the jar out of the cup, and touch an electrified conductor with its knob, and the balls *z* inſtantly ſeparate: I then replace the jar in its cup, and the balls remain ſeparate; but if I touch the knob *a*, the balls *z* cloſe, and the balls *x* open: if I take my finger from *a*, and touch the outſide coat of the jar, the balls *x* cloſe, and the balls *z* open; ſo that if the in and out-ſide of the jar be alternately touched, the balls will ſeparate and cloſe alternately for hundreds of times. Here, then, is a proof that there is an influence operating in, and through, the texture of the glaſs, though we conſider glaſs as a non-conductor. To explain this, it will be neceſſary to obſerve, that by touching the electrified conductor with the knob *a*, the jar became poſitive on its in, and negative on its out-ſide, agreeable to what has been ſaid on the Leyden jar: in this ſtate it was inſulated in the tin cup, by the glaſs leg *s*. I now touch the knob *a*, and carry off (by the conducting power of my body) a portion of its poſitive electricity, and the balls *z* cloſe by that loſs. What, then, has paſſed in the texture of the glaſs? The electricity, forced towards its outſide by the charge, now returns towards the inſide, and leaves the outſide more negative than it was; hence the balls *x* diverge in ſearch of electricity to ſupply their want: I then touch the outſide, and, by ſupplying that want, the balls *x* cloſe: but now the electric matter vibrating towards the inner ſide of the glaſs (with a kind of flux and reflux), a weak poſitive again ſeparates the balls *z*. By touching the knob *a*, the balls *x* again become negative, and expand in ſearch of electricity: and as the ſurrounding air (if dry) is not diſpoſed to part with it, the effort will continue for a conſiderable time, &c. &c.

I conceive theſe to be deciſive experiments in favour of glaſs and other electrics poſſeſſing a ſuperabundance of electricity, *naturally*; of their retaining it with a ſtrong chemical affinity; of its liability to be diſturbed, compreſſed, or forced, by ſtronger condenſations from powerful electrical machines, or lightning; and that forcing this power is ſomething like the forcing wool, or other elaſtic ſubſtances, into a package already full; or compreſſing water into a metallic veſſel, ſo full, that the ſuperabundance muſt be ſqueezed through the metal.

END OF THE FIRST LECTURE ON ELECTRICITY.

LECTURE VIII.

SECTION I.

Of Spontaneous Electricity.

THOUGH this mode of exhibiting electricity appears to be without friction, it is only ſo where it paſſes between bodies containing unequal portions of it. The tourmalin is a red-coloured ſemitranſparent foſſil found in Ceylon, that has the property of ſhewing ſigns of electricity, by being warmed, or heated, differently from other electrics. When heating, one ſide is poſitive, and the other negative; when cooling, that which was poſitive becomes negative, and the other poſitive. Is not this becauſe it is an electric that holds its electricity ſo looſely, that the friction occaſioned among its parts by heat, is ſufficient to excite, and give it motion? If a piece of window-glaſs be laid on a warm poker, and the tourmalin on the glaſs, the glaſs will become negative, and the ſide of the ſtone touching it will be poſitive. Is not this another inſtance of the relationſhip between common fire and electricity? The heat excites the tourmalin, and qualifies it to abſorb electricity from the glaſs; the glaſs of courſe becomes negative, while the foſſil is in a ſtate of condenſation.

Electricity does not appear over the whole ſurface of the ſtone, but only on two oppoſite ſides, like the poles of a loadſtone; ſo that its virtue lies in the direction of its ſtrata, and, therefore, is capable of being forced, or drawn, to or from one pole towards the other, by heating, cooling, or friction. When put in the fire, it covers itſelf with aſhes; when rubbed with ſilk it emits ſtrong flaſhes; and is luminous when warmed in the dark: ſo that changing the degree of heat, is what excites the ſtone.

2d. Sulphur melted in a glaſs veſſel exhibits ſpontaneous electricity; the glaſs is poſitive, the ſulphur negative. If poured into a metal cup, and left to cool, it ſhows no ſigns of electricity; but ſeparated from the cup, the ſulphur is plus, the cup minus. So melted chocolate, as it cools in the tin pans, is ſtrongly electrical. Theſe, and many other ſubſtances, are ſo expanded by heat, that when they cool and contract, a friction takes place ſufficient to excite electricity.

3d. Vapour carries off latent electricity. Place a metal cup, *a*, on the electrometer* *c*, fig. 1, Plate XXXI. with a little water in it; if then a red-hot coal be dropped into it, a vapour will ariſe that will carry off a portion of electricity from the cup, the cap, and the leaf-gold. The leaves will inſtantly part, and fly to the ſlips *s s*, to ſupply their loſs; of courſe they become in a ſtate of want, or in a ſtate of negative electricity: but the wire *p*, held by the ſealing-wax, or glaſs, *q*, in the vapour, will have its pith balls *d*, part with

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* Bennet's electrometer is a cylinder of glaſs, *c*, faſtened into the metal bottom *m*. From the metal cap *z* is ſuſpended two ſlips of leaf-gold, *n n*, about four inches long, and half an inch wide, reaching near the bottom. Two ſlips of tin-foil, *s s*, are paſted to the glaſs cylinder parallel to the leaf-gold.

poſitive electricity. Here it is evident that vapour carries off electricity from water, or whatever elſe it is in contact with; and perhaps the vapour derives its volatility from its union with electricity, for it is obſervable, that if inſulated pith balls be ſuſpended in a fog, or miſt, they ſeparate ſpontaneouſly with poſitive electricity.

4th. If an hollow cone of tin, as fig. 2, Plate XXXI. filled with a quantity of coiled-up wire, be held by the glaſs handle *a*, over the inſulated vapour, or flame of molten reſin and bees-wax, the electrometer balls, *c*, will part with negative electricity; theſe being ſubſtances when excited that attract electricity from the bodies they touch, and therefore are ſaid to produce negative electricity.

Smoke, as well as heated air, reſiſts the paſſage of electricity: flame greedily abſorbs it. Fix a Leyden bottle to the end of a metal rod, which will ſerve as a handle; let the bottle be charged, and paſſed rapidly through the flame of burning paper, ſtraw, or any other combuſtible, and it will be as effectually diſcharged, as if the diſcharging rod made a communication between its out and in-ſide coating: paſs it in the ſame manner through ſmoke, and it will remain charged: but if held charged in an hot oven, it will loſe its charge as before. Do not theſe effects imply the relationſhip between electricity and flame, or fire? Is not flame a conductor from that affinity, and from diſplacing the non-conducting air?

6th The conducting power of flame is beautifully exemplified, by bringing the knob of a charged bottle near the flame of a candle, as fig. 3, Plate XXXI. If the knob *a* communicate with the outſide coating of a charged jar, and the knob *c* with the inſide coating, and each be held two inches from the candle, and oppoſite each other, the flame will ſpread towards each, and a diſcharge will be made through it: ſhewing that the weak negative will make an effort to meet the ſtronger poſitive, as if their power were equal.

SECTION II.

Of Lightning.

THIS might be conſidered under the head of ſpontaneous electricity; for that lightning is electricity, there can be no doubt, from their effects being the ſame. If a kite be held in the wind by a ſmall ſoft iron, or copper wire, inſtead of a ſtring; and the wire be coiled round a ſtrong rod of ſolid glaſs, held in the two hands; ſparks may be taken from this wire, and jars charged as by a common electrical machine. In making this experiment, it is neceſſary to let a key hang by a wire from that which is coiled up, ſo as to touch half-a-crown, or any plate of metal lying on the ground; by lifting the key a little from the plate, a ſtream of fire will be ſeen between the key and the plate. But if a ſenſation, like a cobweb, on the face, takes place, it will be prudent to throw down the glaſs rod, and leave the kite to itſelf. The effect takes place, whenever a kite can be raiſed, and at all times of the year. 2d. If a long wire ſcrewed into the knob of the Leyden bottle, and pointed at its extremity, be held aloft in the open air at night, when thunder and lightning is near, a ſtar will appear on the point;

and if the other hand touch the wire, a ſhock will be received. 3d. I ſtand on a glaſs-footed ſtool, fig. 9, Plate XXXI. with a fiſhing-rod (covered with tin-foil, and with ſeveral points at its extremity) in my hand: if the feet of the ſtool are very dry and clean, when the rod is held out at the window, or up in the air, it ſeldom fails to attract an electric atmoſphere, and put me (in general) in a poſitive ſtate, which is indicated by touching the electrometer, and trying whether the leaf-gold opens with poſitive or negative electricity. A ſmall lighted torch fixed to the fiſhing-rod, as at *c*, aſſiſts the extraction of electricity from the air; perhaps by rarefying the air around it, and thereby relaxing the ſtrong union between the air and electricity; and may account for the lightning always ſeen to dart downward through the flames of Veſuvius and Ætna when in a ſtate of eruption. 4th. Animals killed by lightning, putrify in a very ſhort time; ſo do thoſe killed by electricity: perhaps, in both caſes, by their blood veſſels being ruptured, or by the vacuum formed by the quick deſcent or exploſion of the lightning; for often men and animals have been killed by lightning, when neither wound nor rupture could be found on their bodies.

The identity of lightning and electricity being thus eſtabliſhed, let us try to form a conjecture, from whence it comes and whither it goes. Hitherto we have conſidered light as the primary emanation from the ſun; but as I hope it has been proved that fire, light, and electricity, are but modifications of one and the ſame principle, it is no great deviation from the firſt hypotheſis, to conceive electricity rather as the matter of the ſun's atmoſphere, and which, by its natural repulſion and the ſun's centrifugal motion, becomes projected from him into infinite ſpace, where it meets and mixes with ſimilar emanations from other ſuns; ſo that all ſpace is probably filled with this ſubtil and powerful matter. Though the momentum of light might ſeem (from what has been ſaid on that ſubject) too inconſiderable to give annual and diurnal motion to the planets, here we have an emanating principle, whoſe power is irreſiſtible, and equal to the taſk of giving motion to a world! and perhaps the vivifying ſpirit to its plants and animals. The part of this ſubtil matter that impinges on our earth, meets firſt the uppermoſt region of the atmoſphere, which is a conductor, and admits the fluids (for thin or rarefied air conducts electricity); but as it approaches the lower and more denſe part of the atmoſphere, it meets increaſing reſiſtance, and is often obliged to force its way through the non-conducting lower regions; producing the terrible corruſcations and exploſions of thunder and lightning. For the air being elaſtic, it will give way, and act like a cuſhion to the impetus of ſolar electricity, thereby communicating the electrical momentum more equally to the ſolid earth: this ſtream being probably unequal from croſſing other ſtreams, from ſpots on the ſun, which do not project repellent matter, &c.; for it is now aſcertained that what we call fixed ſtars (which are conceived to be ſuns) are not fixed, but ſeveral have been found to alter both their latitude and longitude in the courſe of an obſerver's life, and therefore their ſtreams muſt croſs differently; ſometimes friendly to the motion of their projected electricity, and ſometimes to its retardation. In the clouds electricity meets with a receptacle (for water admits and conducts it), and when thoſe clouds are not overcharged, the air is in peace. Now if we conſider the clouds as one of the coatings of the Leyden vial, the lower denſe air as the glaſs, or electric, and the earth as the other coating, we may contemplate the Leyden bottle upon a grand ſcale, producing thunder, lightning, earthquakes, and the aurora borealis!

Fig. 3, Plate XXXI, *a*, is a portion of the earth's ſurface; *c*, the lower non-conducting part of the atmoſphere; *d*, the clouds; *g*, the poſitive electricity of the clouds, met by the negative, *q*, of the earth; *n*, the exploſion; *z z*, the electric ſtream from the ſun. When the air is very dry, and much ſaturated with electricity, it reſiſts the entrance of more; and hence the reaſon why thunder generally follows ſuch weather, and is more prevalent in ſummer than winter. When the air is moiſt, electricity finds an eaſy paſſage into the earth, without commotion; and hence the earth has been generally conſidered as the grand reſervoir of it; and from that reſervoir we pump it by electric machines and other frictions, being incapable, by ſuch means, of exciting much from the air. When the rays of electricity, therefore, come the moſt directly on the earth, as in ſummer, a greater quantity may be poured on the dry air than it can conduct, and hence the clouds will be in a condenſed or abundant ſtate, while the earth, comparatively, may be in a negative ſtate; the conſequence will be a violent effort to reſtore equality by a ſtorm of thunder and lightning; and the air near the earth will be found poſitive and negative by fits, while the ſtorm laſts. When the clouds are ſcattered at a diſtance from one another, the lightning is often ſeen darting from one to another, where the air is too rare or thin to form much reſiſtance to its paſſage, and then we ſee lightning without hearing thunder. When the electric ſtream from the ſun falls obliquely on the earth's atmoſphere, as in winter, it is ſeen ſtreaming through the upper regions of the air toward the north, and is called the aurora borealis, ſtreamers, or northern lights. The ſame phænomenon is alſo ſeen towards the ſouth pole of the earth, when the ſolar ſtream darts obliquely upon it, or makes a chord with the atmoſphere. This phænomenon is never ſeen in or near the torrid zone, becauſe the ſun's rays fall direct upon thoſe parts, inducing electricity on the upper, and forcing it through the lower regions of the air into the earth, where it lies quieſcent till called forth by frictions or affinities. One of thoſe affinities is water, to which it adheres with great affection, ſeparating its particles, and giving them volatility. And though they riſe together through a medium, conceived to be already full of electricity, yet as the particles of electricity repel each other, and that repellency is increaſed by the heat the opaque earth receives from the ſun, the evaporation goes on, water riſes through the air flying on the wings of electricity, till it arrives in thoſe cold and rare regions that are conductors of electricity (for air approaching to a vacuum is a conductor). To this rare, or thin air, electricity has a greater affinity than to water; the water becomes forſaken, and its particles attracting each other, form little aſſemblages, at a ſmall diſtance from each other, and appear as clouds. Theſe aſſemblages increaſing, ſoon become ſpecifically heavier than the air in which they float, and begin to deſcend; picking up more, they become drops, and fall to the earth. That evaporation is thus carried on, may be proved by hanging a pair of ſmall pith balls, by flaxen threads, in a receiver, and electrifying them poſitively: if the receiver be placed on the air-pump, and exhauſted, the balls will cloſe; but when the vapour becomes decompoſed, and deſcends in the receiver, the balls open with negative electricity; ſhewing that the rarefied air abſorbed the electricity, and left the water to which it was united: thus forſaken, both by the air and its electricity, it falls, within the receiver, a real ſhower of rain. A precipitation of ſnow is but the above little aſſemblages of water frozen and ſticking together in flakes. This phænomenon is often produced artificially in crowded aſſembly-rooms at Peterſburg, by letting in the cold air from the top of the room, which will ſuddenly condenſe the floating vapours, and make them fall in ſmall flakes of ſnow. Hail is a frozen drop; or often ſeveral drops united into one great hail-ſtone.

That lightning may ſometimes break through the atmoſphere to the earth, when thick clouds, one above another, make a conducting road for it, is very conſiſtent with its nature. Such clouds generally appear when a waterſpout takes place; which begins like a ſpiral pipe from the loweſt cloud, and deſcending towards the ſea is met by a whirling protuberance of water from the ſurface: this I take to be the electricity of the water, making an effort to meet that of the clouds; (for the negative electricity of a charged jar will endeavour to meet the poſitive with as much energy, as the poſitive will the negative). If we, therefore, conceive a ſtrong electricity from the cloud met by a weaker from the ſea; and that the track made both by the aſcending and deſcending electricity will be a vacuum in the air, to which the winds will ruſh in all directions, and form a whirlwind; water, either aſcending or deſcending, in ſuch a vortex, will neceſſarily be formed into a pillar-like figure. When theſe effects take place over the land, we find the earth torn up, as if blown up by gunpowder, and a whirlwind commences at the place. Sometimes the effect is progreſſive; then have we waterſpouts travelling from the ſea, and breaking in a deluge upon the land. When this progreſſive whirlwind happens in a wood, we find viſtas made through it by trees torn up by the roots, broken and thrown in all directions! Such is the power of this wonderful agent.

It is obſerved, that earthquakes only affect the outward ſurface of the earth; that mines, and even wells and ſprings, are little injured by them; and that the tremulous motion is quite external. It follows that they are not occaſioned by *internal exploſion.* (This is to be underſtood of earthquakes that happen at a diſtance from volcanic matter; for internal cauſes may *then* operate.) What power in nature, then, is capable of producing a vibratory motion over many ſquare leagues of the earth's ſurface? I think accumulated electricity. The air preceding the earthquake is always hazy, but not like the hazineſs occaſioned by moiſture; it ſeems ſurcharged with fiery, rather than aqueous vapours. The atmoſphere is of a red colour; the air is ſtill; birds, beaſts, and all nature ſeem aware that ſomething terrible is approaching. The firſt ſhock is as if the earth vibrated to and fro; or, as if waves like the ſea heaved up the earth progreſſively. This cannot be the effect of internal exploſion, becauſe no internal miſchief or derangement takes place. May it not be an overcharged atmoſphere, labouring to diſcharge its electricity into a dry earth, ill diſpoſed for its reception? for dry earth is a tardy conductor of electricity. But earthquakes generally happen on the banks of rivers, or banks of the ſea; and accordingly the water does not receive a vibratory ſhock of the ſame kind that the land does, though the commotion is here alſo violent and irregular, but receiving the electric matter from the atmoſphere at once (as being a good conductor): the effect on ſhips, or bodies in the water, is as if ſomething hard ſtruck the ſhip or the body in the water. For if the hand be immerſed in a glaſs-bowlful of water, when a ſtrong ſhock from an electrical battery is ſent through the water, the hand will receive a blow very unlike an electric ſhock, but very like what I have been told the ſhips in the Tagus felt in the great earthquake of Liſbon.

An humble imitation of thoſe effects may be produced by the two circular boards, fig. 11, Plate XXX. about two feet in diameter, their edges rounded, and the whole covered with tin-foil. Let one be ſuſpended from the ceiling by clean ſilken cords; and the other ſuſtained on glaſs feet, parallel to the other; but ſo as to be brought nearer or farther from one another. If the upper board be connected with the conductor, and the lower with the earth, and ſeparated about two inches diſtant, and electrified; one hand touching the lower, and the other the upper, a ſhock will be received as from the Leyden bottle: for, as has been ſhewn, it is but a plate of air that is charged inſtead of a plate of glaſs; the upper board being in a poſitive, and the under in a negative, ſtate: the ſhock being in proportion to the quantity of electricity, and the eaſe with which it can eſcape from the poſitive ſide of the electric. The two plates ſtrongly attract each other, and would come together, if not kept aſunder by force: ſparks flying between them will frequently deſtroy the electricity of each. If the under ſurface of the upper plate be covered with gilt leather, and a ſmooth ſhilling be laid on the lower plate; beautiful ramifications will fly about the leather, and dart to the ſhilling, when electrified. In this experiment the upper plate naturally repreſents a poſitive cloud, and the under one the earth, with the manner in which lightning darts from the clouds to the earth; and if a Leyden vial be connected with the conductor, as *z*, the flaſh and report will be ſtill greater.

2. A whirlwind, or waterſpout, may be naturally exhibited by laying a ſpoonful of bran on the under plate, and taking off its chain. When the upper plate is electrified, and the hand now and then touches the lower, the bran will aſſemble in one place, and

form a kind of column between the two plates, and whirl round, then ſhift to different parts of the plate, and after ſome time fly off and diſperſe about the room.

Theſe appearances are ſo exactly ſimilar to thunder, lightning, tornados, waterſpouts, &c. that, on the hypotheſis of electricity emanating from the ſun; being received and conducted by the thin air of the upper part of our atmoſphere, to the clouds; and ſtopt there, by the non-conducting denſe air below, from uniting with the earth, to which it has the ſtrongeſt affinity; may we not believe that its efforts to pervade, or get through, the reſiſting air of the lower atmoſphere, produces the above effects?

SECTION III.

Of Animal Electricity.

THAT the animal nerve is a vehicle for electricity, and perhaps the cauſe of ſenſation, many experiments make more than probable. In the torpedo, we find an electrical battery, abſtracted from the veſſels appropriated to the animal functions; it conſiſts of a great number of veſſels like an honey-comb, ſtanding acroſs the fiſh, from its belly, to its back; ſo that if one hand touches the belly, and the other the back, an electric ſhock is inſtantly felt, and the fiſh is convulſed. If the fiſh be touched with a ſtick, a numbneſs ſeizes the hand that holds the ſtick. The ſame effect takes place, if a charged battery be touched with a ſtick, becauſe the ſtick is a bad conductor, and the electric matter can only paſs through it in a ſtream, benumbing the hand in its paſſage; but a regular conducting power from its poſitive and negative ſides, would be a ſhock. The electric eel, or gymnotus, has a ſtronger electrical power than the torpedo: the head and ſhoulders of this fiſh contain the animal functions; the reſt ſeems all electrical; and electrical by volition, for the creature has the power of exerting or withholding the ſhock. If one hand be put in the water, and the other touch the eel, a violent ſhock takes place. I have electrified thirty people at once with this eel; and ſparks have been produced by that electrical circuit. How theſe two ſpecies of fiſh collect and retain their electricity, in a conducting medium, is an inexplicable wonder; they were no doubt endowed with this power for defence, and catching their prey; and have organs to ſecrete it from the water as other animals ſecrete nutrition from the heterogeneous contents of the ſtomach. The nerves ſeem not deſigned to admit, or tranſmit, any animal fluid; they are kept moiſt by an indolent lymph; and are tranſparent acroſs and lengthwiſe, as if intended to give a direct paſſage to *light*. If electricity and light be the ſame (but differing in circumſtances), may not this tranſparency be ſtrongly indicative of their capacity to tranſmit electricity? But this conducting power is proved by the late experiments made on frogs, and other cold animals. This barbarous experiment requires the frog to be divided in the middle by a pair of ſciſſars, and the ſkin taken off. The viſcera of the hinder part is cut away, ſo that the vertebræ may be laid bare: the two nerves will then be plainly ſeen, that give articulation to the hind legs, which being raiſed with a needle, a portion of the vertebræ may be cut away, ſo that the other part of it may be united to the hind legs by the above two nerves; ſee fig. 5, Plate XXXI.; if round the remaining vetebræ a little tin-foil be wrapped, as *a*, and the legs be laid on a piece of zinc or on half-a-crown, as *c*; if by a crooked ſilver wire, *d*, the tin-foil and zinc be touched at once, the legs of the frog ſtart up, and are ſtrongly convulſed. 2d, If the two legs be put in a wine-glaſs, full of water, and the piece of vertebræ wrapt in tin-foil in another adjoining one; ſee fig. 7, Plate XXXI.; and if then the bent ſilver wire *d* touch the water in each glaſs, the legs of the frog inſtantly jump out of the water! Are not theſe ſtrong indications that the influence of the brain and nerves upon the muſcles is of an electric nature? 4th, The nerve of the limb of an animal (recently killed) being laid bare, and its end armed with tin-foil as above; if a communication be made between the tin-foil and any neighbouring muſcle by the ſilver wire or one of zinc, ſtrong convulſions will be produced in the limb. 5th, Or if the metallic communication be made between the armed and bare part of the nerve, the contractions will alſo take place. 6th, A ſimilar effect is produced, by touching the armed part with different metal. 7th, The amputated limb of an animal being placed on a table, and its principal nerve laid bare, and held by one hand, while the other touches half-a-crown, with a piece of zinc (the half-crown lying in the water that communicates with the limb), the limb inſtantly becomes convulſed. 8th, Animals almoſt dead become conſiderably revived by exciting this influence. And if a live flounder be laid on its back, on a plate of copper, and an half-crown be placed on its belly; on making a metallic communication between the two metals, the flounder leaps up. 9th, In animals killed by opium, or corroſive ſublimate, or ſtarved to death, or killed by an electric ſhock, little or no contractions are produced; for a little laudanum laid on the nerves of the above frog's hind legs, made them inſtantly inſenſible, and all muſcular motion ceaſed. Zinc appears to be the beſt exciter when applied to gold, ſilver, molebdena, ſteel, or copper; but it muſt be obſerved, that two different kinds of metal muſt be uſed in making the circuit, ſuch as zinc and gold, ſilver and tin, tin and lead, &c. 10th, If a medal of zinc be introduced under the tongue, and a crown-piece be laid on the tongue, and the edges of the two pieces be made to touch, the nerves of the palate are affected by a ſtrong phoſphoric taſte. 11th, If the piece of zinc be introduced between the teeth and upper lip, near the eye-tooth; and the crown-piece be puſhed far under the tongue; and then the edges of the two pieces be made to touch, a flaſh of lightning is ſeen by the eyes, even though the perſon be in the dark or hoodwinked. 12th, If a perſon ſtand on the electric ſtool with glaſs feet, and touch the prime conductor for a few minutes, while the machine is working, his pulſe will be greatly accelerated; and if bled in that ſituation, the blood will be projected from the vein to a conſiderable diſtance: ſhewing that electricity ſtimulates the motion of the heart, and increaſes this motion of fluids, &c. &c. Can any doubt remain that this wonderful agent is a prime inſtrument in muſcular motion?

That different kinds of metals are neceſſary in producing theſe effects, may ariſe from the different quantities of ſpecific electricity contained in them; gold contains more than ſilver; zinc more than tin, &c.; ſo that when theſe different metals are put together, or come in contact, an inſenſible equilibrium may take place among them; or when they ſeparate, as *a* of zinc, and *b* of tin, fig. 8, Plate XXXI. if a communication be made between them with a wire of gold or ſilver, as *d* (for it is found that the purer the metal, the better is its conducting power), an equality takes place. If a medal of zinc, therefore, be worn in the pocket with ſilver, and inſtantly uſed from that ſituation, they will not produce on the eye the ſenſation of a flaſh of lightning, as above. If one of theſe metals be, therefore, conſidered as plus, and the other minus, may not the equilibrium made between them by the wire *d*, fig. 5, Plate XXXI. put the electricity of the nerves, *z*, into motion, and by that means ſtimulate the expiring muſcles to action?

That different metals contain different quantities of inherent or ſpecific electricity, ſeems evident from this experiment. Take 30 or 40 medals of zink, and as many half-crowns, as A B D, fig. 6, Plate XXXI.; lay firſt a medal of zinc on the table; lay upon it half-a-crown, and on this a round piece of paſteboard moiſtened in ſalt and water, or in a ſolution of ſal-ammoniac; repeat this arrangement till the medals form a pillar with half-a-crown at the top. If a ſilver wire touching the loweſt medal be held in the left hand, and another in the right touch the topmoſt medal, a ſhock like electricity is felt; and if the pile have a wire communicating with the topmoſt medal, as A, that extends into the glaſs veſſel of water B, and comes near the end of a wire D (communicating with the loweſt medal), bubbles of air will be ejected from the ends of the two wires, one being oxygen gas, and the other hydrogen. Or if plates of ſilver be ſoldered to plates of zinc, and theſe united plates be fixed at half an inch diſtance, edge-wiſe, in a trough, ſo that diluted nitrous acid can be retained between them without leakage; a circuit of ſeveral people, taking hands, and communicating with the two ends of this pile, will receive the electric ſhock, the ſame as from the Leyden vial. It ſeems as if *oxydating* one metal, and *unoxydating* the other, excited their latent electricity into action.

Electrophorus.—This apparatus exhibits a continual electricity. It generally conſiſts of a cake, made of a promiſcuous mixture of melted wax, reſin, ſulphur, pitch, &c. made or turned even and ſmooth at the top. A plate of metal, or wood, covered with tinfoil, has a ſolid glaſs rod fixed perpendicularly in its centre, by which it can be lifted. If the wax cake be warmed, and rubbed with dry cats'-ſkin, or flannel, electricity will be extracted by it from the rubber and the hand, and an atmoſphere may be felt on the ſurface of the cake. After excitation, if the metallic plate be placed upon the cake by its glaſs handle, and touched by a finger, when lifted from the cake, the metallic plate will draw a ſpark from the finger. This may be repeated for an hour together, and ſtill the plate will draw a ſpark from the finger. Why?—Electricity is repellent of itſelf: the quantity induced on the cake by friction, repels a quantity from the metallic plate through the touching finger; but in the act of this repellency the plate is lifted from the cake by the glaſs handle, and of courſe left in a negative ſtate (as the electric ſtream is by this means broken): a finger, therefore, approaching the plate, gives it an opportunity of reſtoring its loſs by a draught from the finger. As the cake has only exerted the *influence* of its electricity, and little of the electricity itſelf is loſt or expended, this operation and effect may be repeated for a great number of times; and with a machine, containing inflammable air, candles may be lighted in the night by the electrophorus, as it will retain its electricity for many hours in a dry room. A repetition of placing the plate on the cake may alſo be conſidered as a continued friction and excitation; for the bare removal of cakes of chocolate from their pans, or ſulphur from the moulds into which it has been poured, will excite electricity *.

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* *To Mr. A. Walker, from Mr. Read, on the Electrophorus.*

" Place the electrophorus cake of wax, well warmed, on the table, then rub the ſurface on the palm of the hand, or with a woollen cloth, and the cake will be electrified

Medical Electricity.—“ Fire is the firſt mover in the animal machine, and the chief active principle during its exiſtence; and as electricity exhibits ſo many phænomena which cannot be diſtinguiſh-

negatively; which may be proved by preſenting the excited ſurface to a pair of pith-balls. Hence I conſider the negative electricity of the cake to be inceſſant in its endeavour to obtain the poſitive electricity; and that nothing elſe can poſſibly reſtore an equilibrium to all its parts. But the condition or texture of the cake does abſolutely prevent it from receiving at once all the electricity it wants; yet the mode of repeating the experiments with the cake are all favourable to, and do, in a very ſlow manner, promote its electrical equilibrium.

“ Let us now proceed with the experiment, and place the braſs plate cover, by means of its glaſs handle, upon the cake, and we ſhall find if the glaſs handle inſulate the braſs plate perfectly, that the plate, as well as the cake, will be electrified negatively; of courſe, they have no electricity to give, but very eager to receive the poſitive electricity from any thing.

“ I now approach the braſs plate with my finger, and as ſoon as it comes within the ſphere of the negative attraction of the cake and plate, the finger, though uninſulated, will acquire thereby the poſitive electricity, and a ſpark will iſſue from it into the braſs plate; the quantity, I will ſuppoſe, is equal to both their wants: but it cannot at once, as before ſaid, diffuſe itſelf into the cake, owing to its natural incapacity to receive it; and alſo ſomewhat becauſe the braſs plate touches the cake but in a very few points.

“ After the braſs plate has been touched with the finger lying on the cake, it acquires the poſitive ſtate of electricity, which may be proved in the uſual way; and when it is removed from the cake by its glaſs handle, it ſtill retains, I will ſuppoſe, ninety parts out of one hundred, of the poſitive electricity given to it by the touch of the finger; and which the finger will receive back again, on its approach to the edge of the braſs plate.

“ In this manner, a great many ſparks of electricity may be given to and taken from the braſs plate, by the uninſulated finger only. For not a particle of electricity ever comes into the braſs plate from the cake. The cake and the braſs plate being in the contrary ſtates of electricity, they conſequently mutually attract each other, and their whole tendency is to unite their powers.

“ To illuſtrate one of theſe facts, I would inſulate a large metallic conductor, and touch it with a negatively-charged bottle. This done, it is evident that the conductor muſt be in the ſame electrical ſtate with that of the excited cake of wax. But they differ conſiderably in their compoſition. Therefore it is, when I approach the coned from thoſe of fire, we are naturally led to conceive high ideas of the importance of this fluid to medicine." The agency of electricity in animated nature, has been proved by the experiments made on the torpedo and electrical eel. The number and magnitude of the nerves, in theſe animals, bear no proportion to their ſize; nor do they ſeem neceſſary for their motion, ſubſiſtence, or generation: it therefore ſeems to follow, that they are intended for the formation, collection, and management of the electric fluid; and no doubt to procure ſubſiſtence, and protect the animal from its enemies; particularly as the will of theſe animals commands theſe powers. Variety of facts clearly prove the electric fluid to be eſſentially connected with the human frame; it will dart from long hair when combed in froſty weather; it will inflate a ſilk ſtocking when drawn from the leg. In damp and hazy weather, when electricity is carried off from bodies by humidity, our ſpirits become languid and our ſenſibility leſs acute; the nerves loſe their tenſion and elaſticity: and on high mountains ſpontaneous flaſhes have darted from the fingers, the body containing more than the ſurrounding rarefied and conducting air: an electric ſhock has given tone to a flaccid fibre; has rendered palſied limbs plump: the electric aura from a wooden point has diſperſed an infant cataract in the eye; and when iſſuing from a metallic point, has reſtored the languid circulation of a local part to the condition of the reſt of the body. Inſulated, and connected with the conductor, the pulſation

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ductor with my finger, and a ſpark iſſues out of it into the conductor, that this one touch alone reſtores the equilibrium to every part.

" Laſtly, Philoſophers, in their explanations of the facts and appearances obſerved in the action of an electophorus, have, without reaſon, I think, embarraſſed their account with the doctrine of repulſion. However, I perceive no repulſive power at all. The attraction of the negative ſurface of the cake is, therefore, alone active in this caſe."

" JOHN READ."

is increaſed: by this mode, both male and female obſtructions have been removed. Sparks adminiſtered to chilblains, have, in aſſiſting the circulation of the blood, generally effected a cure. Even the laſt effort of expiring life is called into action by electricity, when every other ſtimulant has failed. Can we doubt, then, that this vital fluid is *much connected with muſcular motion?*

If a battery be diſcharged through a mouſe from the head to the tail, it will kill the animal: but after death, if an equal charge be ſent the ſame way, it will paſs viſibly over the body of the mouſe, and not through it: proving that the power or medium which tranſmitted the ſhock was loſt with its life.

For the application of electricity, it is neceſſary to have a Leyden jar, like fig. 20, Plate XXXII. where the knob *b* is inſulated from *a*, by the glaſs ſupport *c*; and the braſs rod *b d* will ſlide eaſily through the metallic ſocket *e*, ſo as to make the ſhocks greater or leſs. A pretty large forceps, A, ſhould accompany this jar, turning on the joint *g*; and having its legs *n n* of ſolid glaſs rods. This forceps applies to any part of the body; thus: Suppoſe ſhocks are wanted to quicken a languor of circulation in the upper part of the arm; place the knob *r* on the ſhoulder, and the knob *s* near the elbow, and ſlide the knob *b* within a quarter of an inch of the knob *a*, having the wires or chains, *y* and *z*, as in the figure; if now the chain *u* be connected with the conductor, and the machine be excited, the fire will jump from *a* to *b*, and the part will receive a ſhock in proportion to the diſtance of *a* and *b*.

But a better effect is produced by letting the charge paſs in a ſtream through the part. Draw *b* from *a* as far as the ſocket *c* will admit; and diſengage the wire *z* from the knob *s*; this knob when unſcrewed from the forceps, ſhould diſcover a point at *s*. If now the knob *r* be placed on the ſhoulder, and the point *s* be brought near *a*, the fluid, condenſed in the jar, will flow through the arm in a denſe flow ſtream, and produce a conſiderable degree of warmth.

EXPERIMENTS,

MISCELLANEOUS AND ENTERTAINING;

ILLUSTRATIVE OF THE AFORESAID DOCTRINE:

BEFORE we proceed to the experiments, it will be neceſſary to reconſider the electrical machine.

1ſt. *To ſhew the courſe of the electric fluid.*

Fix into the remote end of the poſitive conductor *c*, a wire about ſix inches long, with a ſmall ball at its extremity: excite the machine, and hold the flame of a wax taper near the ball, and the flame will be puſhed horizontally from the ball, in the direction of the electric fluid. Remove the wire and ball into the end of the negative conductor, and the flame will be puſhed towards the ball: ſhewing that the exciting rubber draws the electric fluid from the earth, and air; and that it iſſues from the poſitive conductor.

2d. *To make electric attraction and repulſion ocular.*

Fix a pointed wire perpendicularly in the poſitive conductor, and let another pointed wire, from the negative conductor, approach it within an inch, and directly over it. When the machine is worked, both points will be luminous; the poſitive, or delivering point, with a bruſh; and the negative, or receiving point, with a ſtar. If now an excited tube of glaſs be brought near the poſitive point, its bruſh will be repelled ſidewiſe (for they are both poſitive); and if the excited tube be held juſt oppoſite to the point, the bruſh will inſtantly vaniſh: but the excited tube being held near the negative, or receiving point, its ſtar will turn towards the tube, and be viſibly attracted. As excited ſealing-wax abſorbs electricity from its rubber, or other bodies with which it comes in contact, if it be held near the bruſh it attracts it, if near the ſtar, it repels it, contrary to the effects of the excited glaſs.

3d. *The electrical ſpider.*

Cut a ſmall piece of pith, or cork, into the ſhape of a ſpider; run a threaded needle lengthwiſe through it ſeveral times, cutting the threads, ſo they may hang from each end of the cork; ſee fig. 12, Plate XXXI.; let the ſpider be hung from the ceiling by a dry ſilken thread, and the charged vial placed with its knob near it; the ſpider will then be attracted to it, and becoming poſſeſſed of poſitive electricity as well as the vial, will be repelled to the knob *d*, where it will deliver its electricity, and of courſe be attracted to the knob *b* again. Thus will it continue to carry the poſitive quantity piece-meal from the in, to the out-ſide, till an equilibrium is reſtored between the two ſides.

4th. If a wire with an hollow light ball at each end be ſuſpended on a point ſupported by the glaſs rod *n*, fig. 12, Plate XXXI. and a metallic rod, *s*, ſtand near it, on the ſame ſide with the charged jar; the knob *c* will be attracted to the knob *b*, and receive a ſmall portion of its electricity, and therefore be repelled; but that repellency will drive the knob *g* to the rod *n*, where it will deliver its electricity, which will find its way to the negative ſide of the jar along the wire *z*. Thus will the ſuſpended wire vibrate between the jar and the rod *s* for ſeveral minutes, till the jar is exhauſted.

5th. *Poſitive and negative ſides of Leyden jars, proved by the double jar.*

Let *m*, fig. 11, Plate XXXI. be a ſmall jar ſtanding on a round plate fixed into the knob of the large jar *n*. Let the outſide coating of the ſmall jar, *m*, touch the prime conductor ſo long, as to charge the large jar *n*; then draw both from the machine. The lower jar is now charged: but the upper one is not charged; becauſe, though its outſide coating communicates with the poſitive ſide of the under jar, it cannot be charged itſelf, ſince the knob of its inſide ſurface communicates only with the non-conducting air (for a jar cannot be charged poſitively, on either in or out-ſide, except its oppoſite ſide communicates with the earth directly or indirectly). If now the crooked wire *s* touch the negative ſide of the lower jar *n*, and its other end touch the nob *x*, a portion of the natural quantity of the ſmall jar will be forced out, by the poſitive quantity on its outſide, with a flaſh, and report. The upper jar now becomes charged; for its inſide is negative, from what it has parted with; and its outſide poſitive, from communicating with the poſitive ſide of the lower jar. If then the bent wire *u* touch the knob *x*, and its other end the outſide coating of *m*, a flaſh will take place at *z*. Now what was taken out of *m*, is reſtored from the lower jar, and *m* may be ſaid to be again in its natural ſtate. But if the wire *s* again touch the jar *n*, and its other end the knob *x*, the quantity taken out of *n*, and put into *m*, will exhibit a flaſh at *x*, in its way to the negative ſide of *m*. A little more may be taken out of *n* by touching the knob *x*, and then the outſide of *m*, as before; and this again reſtored to the outſide of *n* by the wire *s*. By repeating theſe, more than twenty flaſhes may be produced while the electric matter is thus ſlowly exhauſting from the lower jar *n*.

6th. *By a ſmall pyramid, to prove the danger of breaks, or interruptions, in thunder rods.*

Let a wooden pyramid, fig. 10, Plate XXXI. be made in ſeveral pieces, with a wire through each, ſo that their ends may touch, as *s s s*. Let one corner of the pedeſtal *d* be looſe, and have the ſafety-wire paſs almoſt through it, but not quite. The wire paſſing through the reſt of the pedeſtal, muſt join (by a chain) the outſide coating of a Leyden vial. If the cloud *x* be ſupported by a wire from the prime conductor, and hang half an inch from the knob *g* of the pyramid; when the vial is charged, a flaſh will take place between *x* and *g*; the lightning will paſs along the wires *s s s*, till it comes to the break at *d*; there an exploſion will take place, that will drive out the corner ſtone *d*, and let down the fabric.

7th. *An electrical exploſion diſplaces the air.*

Shape an half-inch board like the gable end of a houſe, as fig. 13, Plate XXXI.; fix it perpendicularly on the board *d*; cut the ſquare hole *a* through it, and cloſe up the back part of it with a ſquare piece of window-glaſs. Cut a piece of board, that will looſely fit the ſquare hole, and fix a wire diagonally into one ſide of it, as *c n*. A wire, *x n*, terminated by the knob *x*, alſo is fixed ſuperficially into the gable, as well as the wire *c z*. If now the knob *x* be placed within an inch of the prime conductor *k*, joining the vial *v*; and the outſide coating join the wires by the chain *q*; as the jar is charging, a flaſh will take place between the prime conductor *k* and the knob *x*, but no miſchief will be done; for there is a regular road for the fluid along *x n c z q v* to the negative ſide of the vial. But let the ſquare piece of wood be taken out, and its wire placed againſt the glaſs on the back of the hole, and in the direction *a s*, inſtead of the direction *c n*; when the ſtroke takes place from the prime conductor, the ſquare piece of wood will be thrown out to a conſiderable diſtance by the exploſion behind, as may be ſeen through the glaſs: and, that the ſwelling of the air was the cauſe, may be felt by fixing the ſquare piece *o* in the hole; this piece has a ſmall tube fixed in it, ſo that when the exploſion takes place, the hand held before the tube will feel a blaſt of air ſtrike it.

8th. *A further illuſtration of the theory of the Leyden bottle.*

Inſulate the bottle, as fig. 14, Plate XXXI. Hang three bells and two clappers to a wire *a*, communicating with the interior coating; and three others to be faſtened to the exterior coating: hook the chain *q* to the wire *a*, ſo as not to touch the table, and charge the jar as uſual from the ſame wire: while it is charging, the bells hanging from *b* will ring. When the bottle is charged, remove it from the machine, and unhook the chain *q*, and let it lie on the dry table. Now touch the wire *b*, and its bells will ceaſe, and the bells from *a* will begin to ring; then ſhift your finger to the wire *a*, and the bells from *b* will act, and ſo on, alternately, till the bottle is exhauſted. In the firſt caſe, the bells from *b* rung by electricity, propelled from the outſide coating, making its way through the chains of the outſide bells, by the clappers, to the middle bell; from whence the chain *d* conveyed it to the ſurrounding bodies. The apparatus now removed from the machine, and the chain *q* from the wire *a*; on *b* being touched, the propelled electricity returns in part to the outſide, and repels a proportionate quantity from the inſide, which rings the bells on *a* in its paſſage. When the knob *a* is touched, more of the poſitive quantity eſcapes, and more returns to the outſide, ringing the bells in its return, and ſo on, alternately, till the bottle is diſcharged.

N. B. If the ſilk thread *s* be very clean and dry, there will be no occaſion for hanging the chain *q* on *a*, the jar will charge without it; for it would be found rather difficult to take the chain *q* from *a*, without diſcharging the jar and receiving a ſhock.

9th. *The effort of poſitive and negative quantities to meet each other may be ſeen in an overcharged bottle.*

Hold the knob of a Leyden bottle, *a*, fig. 1, Plate XXXII. to the prime conductor, while the bottle is charging, in the dark: when it is nearly charged, little flaſhes and corruſcations will appear at *c*, and all round the edge of the outſide coating: bruſhes will alſo iſſue from the cork of the bottle at *d*, and ſtrive to meet the flaſhes at *c*; if the excitation is continued, they will meet, and a ſpontaneous diſcharge will take place. But if the uncoated part of the bottle be breathed upon, and then held to the conductor as before, the negative quantity from *c* will ſolicit the poſitive from the cork; and the poſitive will incline with equal affection from the cork to meet the negative, and their union may be ſeen at *n*; while the ſuper-quantity will fly off in a bruſh at *m*. If the bottle, fig. 2, Plate XXXII. (held by its knob), be preſſed againſt the prime conductor, while it is charging, negative corruſcations will bend from the cork to meet the poſitive ſtream iſſuing from the outſide coating, and they will viſibly meet without report, at *n*; the quantity running over, iſſuing out at *m*.

10th. *From what ariſes the beautiful corruſcations among the links of a chain, when the Leyden bottle is diſcharged through them?*

The exploſions that take place at the links of a chain are occaſioned by the electrical repulſion of each other, for they, in reality, do not touch. When, therefore, a chain is tightly ſtretched, an electric ſhock will paſs through it, as through a wire, without any lateral exploſions.

11th. *Has electricity any weight?*

Yes.—Suſpend a ſmall thin glaſs balance on a fine point, *a*, fig. 44; balance the hollow knob *c* with the weight *d*, and let *c* juſt touch the prime conductor *w*; which being electrified, the end *c* will be found to preponderate: in this caſe, the convex parts of the knob and conductor muſt be exactly oppoſite, that the momentum of the aura may be equal on all ſides.

12th. Tranſparent bodies are, in general, non-conductors of electricity; as air, glaſs, ſilk, &c. But electricity is capable of making many opaque bodies tranſparent by impregnating them with temporary light. If the ends of two chains, in an electric circuit, be placed at a quarter of an inch from each other, and a finger be laid at the interruption ſo as to touch each; when an electric ſhock is ſent through the wires in the dark, the finger will be ſeen perfectly tranſparent. A piece of ivory laid on the interruption will alſo become tranſparent, &c.

13th. If ſtrong ſhocks be ſent through a glaſs tube filled with vitriolic acid, ſulphur will appear on its ſurface. Is not this favourable to the old doctrine, that ſulphur is but a combination of that acid with phlogiſton (or what I call fire)? For we procure the acid by burning brimſtone; thereby diſengaging the acid, which forms an union with water placed in leaden veſſels for its reception. What effect, then, does the electricity produce when ſent through this acid, but reſtore the fire, or phlogiſton, which the ſulphur loſt in burning?

14th. *Electricity adds bulk and inflammability to air.*

Fill a bent tube, fig. 4, Plate XXXII. from *a* to *b*, with heavy inflammable air, and the reſt with quickſilver, inverting one end of the tube in a baſin of quickſilver, and corking up the other, with a wire *c*, through it. If ſtrong electrical ſhocks are paſſed through the tube, the air will increaſe in bulk, and becomes ſo *carolified* as to burn as clear as vital air. 94.5 meaſures of this gas, mixed with 107.5 of oxygen gas, being fired in a cloſe veſſel, were reduced to 128.5 meaſures. Was not this from the eſcape of its fire, or electricity?

15th. A fleecy feather, ſuſpended by a fine ſilken thread, and addreſſed to an electrified tube of glaſs, or ſtick of ſealing-wax, will be attracted by the excited tube or wax, and inſtantly repelled: but in that repellency, if the tube be moved round the feather, the feather will move round the tube, *and always keep the ſame face to the tube*, juſt as the moon keeps the ſame face towards the earth. I do by no means, however, contend here for the cauſe being the ſame.

16th. A black-lead line, on paper, is a conductor: if that line be made into an electrical circuit, after being covered with powdered roſin, it will produce an amazing illumination.

17th. Electric ſparks will not take place but in mediums that are bad conductors. All airs are bad conductors, except the inflammable; in this air no ſparks can be taken. Does not this favour the hypotheſis, that metals, water, and other bodies containing fire, that are conductors, and holding their inherent or ſpecific electricity but looſely, derive their conducting quality from that property?

18th. *Electricity gives volatility to water, and is, perhaps, the principal agent in the riſe of vapour.*

On Bennet's electrometer, fig. 5, Plate XXXII. place a ſmall metallic cup *d*, with a few drops of water in it: if a live coal be dropt into it, the ſlips of leaf-gold will part with negative electricity; and ſhew that electricity was carried off from the cup and cap of the electrometer *a*, by the riſing vapour; and that the ſlips went to the pieces of tin-foil, *c c*, to recruit their loſs.

19th. The electricity of fogs and rain is well illuſtrated by two of the above electrometers, fig. 6, Plate XXXII. The cap of the electrometer A, has a bent wire, *m*, ſcrewed into it, having at its other end a piece of tin, *s*, ſoldered to it: another electrometer, B, has the metal cup *d* placed upon it (as in the laſt experiment), and directly beneath the tin *s*. If water from the jug *g* be poured on hot coals in the cullender *c*, the water that falls into the cup *d* will produce negative electricity in the electrometer B; and the vapour that riſes againſt *s*, will induce a poſitive effect in the electrometer A. Is not electricity thus carried into a latent ſtate like fire, or heat? Is it not evident that the ſteam had acquired what the water had loſt? and that this is another inſtance that fire and electricity produce the ſame effects, and, conſequently, that they are but modifications of one and the ſame principle?

20th. This fact may be further diverſified by fixing a tobacco-pipe to the cap of an electrometer, as *a*, fig 7, Plate XXXII. If the ſmall end of this pipe be heated red, and fixed as in the figure: if water be poured into it, it will riſe in ſteam againſt *s* (as in the laſt experiment), and produce poſitive electricity in A, and negative in B.

21ſt. A ſmall bucket of water, with a capillary ſyphon in it, hung to the conductor, will diſcharge the water in drops: but when electrified, the water will diverge, flow ſwifter, fly about in ſmall drops, and be luminous. Or ſuſpend one bucket from the poſitive conductor, and another from the negative, with their ſyphons within three inches of each other; when electrified, the ſtream iſſuing from one will be attracted by the other, and form one ſtream, which will be luminous in the dark. If the two buckets are ſuſpended on two poſitive, or two negative conductors, the ſtreams will repel each other. Or if water be poured into a baſin, placed on the prime conductor, the ſtream will divide into a great number of lucid drops.

A ſponge, filled with water, and hung to the conductor, when electrified in the dark, will exhibit fiery rain.

The knob of a charged bottle will attract a drop of water from a baſin; which drop, on the removal of the bottle, will aſſume a conical ſhape, and if brought near any conducting ſubſtance, will fly to it in luminous ſtreams.

Theſe experiments prove that water is ſeparated and diſſipated into vapour by electricity, and that with uncommon rapidity.

22d. Sparks taken from electrified water, carry off a portion of that water along with them. Place a drop of water on the prime conductor, and it will deliver a very long ſpark, aſſume a conical figure (like a water-ſpout), and wet the body that receives the ſpark.

23d. Heat one end of a thick wire, ſo that it will make its way into a ſtick of ſealing-wax; the wax may then be made to project horizontally from the prime conductor, ſo as to be eaſily ſet on fire by a taper; if electrified whilſt it is blazing, filaments, like fine threads, will dart from it the length of a yard or more, and cover a ſheet of paper, held before it, with innumerable fibres like a cobweb. This is but the riſe of vapour in another, but a more tenacious fluid; where, by the heat of the flame, and the repulſion of electricity, the parts are thrown out into long threads.

24th. If two bottles, *a* and *b*, fig. 9, Plate XXXII. having ſmall tubes fixed in their corks, with each a ſtop-cock, be half filled with water, and the cocks be open, the mouth applied to the tubes may eaſily, by blowing, ſo condenſe the air within, that by its preſſure on the water, fountains will take place. If theſe bottles, ſo charged, and the cocks ſhut, be one placed obliquely on the poſitive and the other on the negative conductor, and whilſt electrifying, the cocks be opened, the fountains will lean towards each other, coaleſce, and fall down in large drops, as in the figure.

Theſe experiments ſtrongly indicate, how poſitive and negative clouds attract, unite, and mix their waters together, ſo as to produce drops.

25th. *How can the motion of the earth be repreſented by electricity?*

Fix the wire hoop, fig. 10, Plate XXXII. *a a*, into the prime conductor *d*, and place a braſs plate, *c c*, on a ſtand half an inch below the hoop; then lay a thin hollow glaſs globe, about three fourths of an inch diameter, on the plate, and electrify the conductor; the ball will inſtantly begin to turn on its axis, and roll round the hoop.

26th. *May not electricity be the cauſe of tranſparency?*

Let one end of a chain be connected with the outſide of a charged jar, and its other end lie on the table: place the end of another chain about half an inch from it, and place a decanter of water on theſe ſeparated ends. If now the jar be diſcharged through theſe chains, in the dark, the water will appear beautifully luminous.

Does not this ſeem as if light lay latent in the glaſs and water; and was excited into viſibility by the exploſion made under the decanter? Or lay the end of a finger between the two ends of the wires, and the ſhock will render the finger tranſparent. So it will an ivory ball, &c.

27th. *How to repreſent words, trees, landſcapes, &c. by electricity.*

Let a glaſs tube of about eighteen inches long, and three fourths of an inch diameter, have ſmall round pieces of tin-foil paſted upon it, at a ſmall and equal diſtance from each other, in a ſcrew-like form, as fig. 11, Plate XXXII.; and let this tube be encloſed in another, to protect the tin-foil: on the ends of this tube there muſt be cemented braſs caps like knobs. When either of theſe knobs are held within an inch of an electrified conductor, ſparks will dart to it, and through the pieces of tin-foil, making an appearance like a ſpiral ſtring of diamonds, the whole length of the tube.

2d. Short words may alſo be made luminous, by covering a piece of window-glaſs with ſtrong copal varniſh, and while wet laying on ſlips of tin-foil parallel to each other, at about two tenths of an inch diſtance, each about the twelfth of an inch wide. When the varniſh is dry, the ſlips may be cut in the ſhape of letters with the point of a ſharp pen-knife, ſee fig. 12, Plate XXXII. The round piece *a* muſt be held near the knob of the conductor, where the fluid will enter and run to *c*, where a croſs-piece of tin-foil muſt conduct it to *o*; from thence it will run back along the line *o g*, and ſo zig-zag to the thumb, which holds the glaſs at *w*. At every cut made with the knife, a ſpark will take place, and all at the ſame inſtant; ſo that in the dark the word will read in diamond-like letters.

3d. Flowers, trees, landſcapes, &c. may be drawn in the ſame way, ſee fig. 13, Plate XXXII.; and their beauty and brilliancy exceed all deſcription.

28th. *How to increaſe the circulation of the blood, and the pulſation of the heart.*

Let the perſon ſtand on a ſtool with glaſs feet, and take hold of the conductor, or a chain connected with it; he will then himſelf become a part of the conductor; and when the machine is put in motion, he will feel his hair ſpread out, and ſtand erect: his pulſe will be accelerated; and if he ſhould be bled in that ſituation, the blood would be propelled to an unuſual diſtance; diverge into ſmall drops, and each drop be ſeen luminous in the dark. In this ſituation he will attract light bodies; give ſparks to his neighbours wherever they touch him; charge Leyden jars; and fire warmed ſpirit of wine with his knuckle. To make theſe entertaining experiments ſucceed well, the inſulated perſon ſhould be careful that no part of his clothes touch the floor, table, or ſpectators; and if the ſtool ſtand on a ſheet of brown paper, the inſulation will be ſtill more complete.

29th. *Electricity ignites combuſtible bodies, like common fire, or lightning.*

Wrap cotton wool round one of the knobs of the diſcharging rod, and fill the wool as full of ſmall bruiſed roſin as it will hold. Diſcharge a jar with the rod as uſual (only obſerve that the covered knob touch the knob of the jar); and the roſin will be inſtantly in a blaze. See fig. 19, Plate XXXII.

2d. The inflammable-air piſtol affords a better inſtance, how liable all inflammable bodies are to become ignited by electricity. This piſtol is ſometimes of braſs, and ſometimes of ſtrong glaſs, as *a*, fig. 14, Plate XXXII.; *c* is a braſs cap and cork, in which is inſerted a glaſs tube, *s s*, through which paſſes a wire, with the knob *n* on one end, and the other, turning at *g*, comes within the tenth of an inch of the braſs cork; ſo that when the knob *n* takes a ſpark from the conductor, the ſpark is repeated at *g*, which fires the inflammable air in the body of the piſtol, and drives out the cork *u*, with a ſtrong flame, and a loud report. This piſtol is charged, by being placed as fig. 15, Plate XXXII. on a bottle containing bits of iron, nails, or filings, on which if vitriolic acid be poured, diluted with eight times its quantity of water, the inflammable gas will be extricated; from its ſpecific lightneſs it will riſe into the piſtol, and mix with the common air in it. After a minute, the cork *u*, may be put tight into it, and it is then fit to be diſcharged.

If, inſtead of common air, vital air be mixed with the inflammable air, the flame and report will be vaſtly increaſed.

A drop of ſtrong æther, corked up in the piſtol an hour, will as effectually charge the piſtol as the above airs.

To imitate the blowing-up of a magazine of powder by lightning, have the ſmall model of a houſe, as fig. 17, Plate XXXII. the ſides and roof faſtened to each other by hinges. Through the board that forms the floor, have a hole for the wires *s* and *u* to paſs through; and alſo a cork *m*, glued on the floor, for the ſame wires to paſs through, ſo that their ends may nearly meet at *x*, above the cork. On this cork muſt be preſſed the bottle B, charged as before with inflammable air. If then the chain *y* be attached to the outſide of a charged jar, and the chain *w* touch its knob, the charge will paſs through the wires *s* and *u*, make an exploſion at *x*, ſet fire to the air, which will blow up the bottle, and with it the roof of the houſe.

30th. *That electricity vibrates like other fluids, ſometimes leaving the body poſſeſſed of it in a poſitive, and ſometimes in a negative ſtate.*

If a coated pane of glaſs be fixed perpendicularly on a board, by the part uncoated (for two inches round its edge is always left uncoated on both ſides); if one ſide be then ſuddenly touched by the knob of an exhauſted bottle (i. e. charged negatively), both ſides of the pane will be found in a ſtate of want, or negatively electrified. By the exhauſted bottle touching the coating of the pane, it ſteals from that ſide of the pane a portion of its natural electricity; the other ſide vibrates towards it, to reſtore the loſs, and both ſides become, of courſe, negative.

31ſt. Let two ſmall pith balls hang from the outſide coating of a Leyden bottle, and its knob be ſlightly touched by the poſitive knob of a charged bottle; the balls will part with negative electricity: but if their bottle be placed on an inſulated ſtand, and its knob again touched by the poſitive knob of a well-charged bottle, the balls will part with poſitive electricity. Why?—Glaſs being conſidered as pervious to the influence of electricity (as above), the poſitive quantity induced on the inner coating of the inſulated bottle will propel from the outſide a proportional quantity, and would make that ſide negative as above, if the matter could get away; but being impriſoned by inſulation, the influence vibrating from the in to the out-ſide of the glaſs, and there ſtopt, both ſides remain alike poſitive.

A bottle charged at the negative conductor, and treated ſo, would have its two ſides negative.

32d. Place a charged bottle on an inſulating ſtand; bring the knob of a bottle well charged negatively, near it; and a thread will play between the two knobs: but, when the knobs touch on the ſtand, the thread will be firſt attracted, and then repelled, by both: for as want was more predominant than abundance, in the two bottles, when an equilibrium was made by their contact, they become both negative. But if a finger touch the knob of the bottle charged negatively, it inſtantly becomes poſitive, ſtealing with ſuch rapidity what it wanted, that more than an equilibrium vibrates from the finger to the bottle; for, like other fluids when in motion, it cannot ſtop in an inſtant.

33d. *The electric matter when its equilibrium is affected, or diſturbed, always chooſes the neareſt road, and the beſt conductors, to reſtore its equality.*

I make a chain of ſmall links into the initial of my name, fig. 16, Plate XXXII. and attach the wire *w* to the outſide of a charged jar, making a continuation of the wire *x* to touch the knob. In the dark, a luminous W is ſeen; (for a lateral exploſion takes place at every round link, from the difficulty that electric matter has of penetrating round or flat bodies). But if the wire *n m* be laid as in the figure, it makes a nearer road, the fire paſſes inviſibly through it, and only is ſeen in half the W, *m z y*. Inſtead of the wire *n m*, if a piece of dry ſtick be laid in its place, the electric matter will take a longer circuit, rather than go through a bad conductor; it therefore rejects the ſtick, and paſſes through the whole W.

34th. Metal is a better conductor than water; as may be proved by beating a hole, with a ſharp iron point, in the bottom of a three-ounce vial, fig. 18, Plate XXXII. at *a*; in this hole muſt be cemented the wire *c p*. The vial is then filled carefully with water, and corked tight, and through that cork a wire paſſes within one tenth of an inch of the wire *c*. The vial muſt be placed on a ſoup-plate. If now the wire, or chain, *n*, touch the outſide coating of a charged large jar, and the chain *s* its knob, an exploſion will take place between the two wires at *c*, that will break the vial into the moſt beautiful ſtriated ramifications.

35th. The effects of an earthquake at ſea, are well imitated by a looſe building of boards, placed on a little boat in a baſon of water: if the water be made part of an electrical circuit from a battery, the report will be remarkably loud; the flaſh along the ſurface of the water, extremely vivid; the building will be thrown down; and a hand put in the water, will feel a diſagreeable ſenſation not unlike a ſhock.

36th. Poſitive and negative electricity mutually attract each other. Balance the round board, fig. 6, Plate XXX. by ſilk cords, on one end of a ſcale-beam, and connect it by a ſmall wire to the prime conductor. If another board be placed under this, at about a foot or fifteen inches diſtance; when the upper board is electrified, it will draw towards the lower, and when at about an inch diſtance, an equilibrium will be reſtored, with a brilliant flaſh and loud report.

37th. The earth ſeems the goal to which electricity has a natural tendency, whether coming from the Sun, its ſource, or whether diſturbed in, or extracted from, the air, or earth, by machines. No ſooner, therefore, is a conducting body, communicating with the earth, preſented to a charged conductor, than its electricity makes an effort to ſeize that body; not merely becauſe it is a conductor, but becauſe it leads to the place where the fluid wants to diſcharge itſelf. This may be ſeen by preſenting the ſame conducting ſubſtance, *inſulated*, to the charged conductor, when only a ſmall ſpark will be produced. So lightning ſtrikes a tree, a houſe, or a thunder-rod, not becauſe theſe objects are high, or in the neighbourhood of a charged cloud, but becauſe they communicate with a part of the earth which then happens to be in a negative ſtate, and to which the lightning would dart, though none of the above objects were in the way to reſtore an equilibrium.

This in nowiſe invalidates the uſe of thunder-rods; as lightning will always take the neareſt road, and the beſt conductors. If the lightning aims at the negative earth on which a houſe ſtands, the houſe will be ſecured by the conductor, and demoliſhed without it.

38th. That electricity may be condenſed or rarefied, like other fluids, is evident, from uniting a metal mug with the prime conductor, when it is placed on the inſulating glaſs-footed ſtool: for if then a pair of pith-balls, ſuſpended by flaxen threads, be connected with the mug, and a chain be dropt into the mug by a ſilken thread, and all electrified, the balls will diverge; but if the chain be gently drawn out by the thread, the balls will collapſe; when let down again, they will diverge, &c.; ſhewing that the electricity is rarefied and condenſed alternately, as by the extenſion of the chain the ſurface is increaſed, and by its contraction diminiſhed.

This implies that we ſhould not be ſurpriſed when we ſee the ſmall effect a fog has upon the inſulated pith-balls, when they are ſuſpended at the end of a fiſhing-rod; the electricity which aſſiſts the riſe of this vapour is too rare to affect the balls much, though they are a little: but a cloud, inſulated by a dry body of air underneath it, and its electricity condenſed by a continual addition compreſſed into it, by the ſolar ſtream, makes efforts to arrive at the earth, to which the utmoſt power, accumulated by art, is but as the ſtroke of a feather to that of a cannon ball.

39th. To fire gunpowder by electricity. Fix a ſmall cartridge on a pointed wire (which ſhould be fitted to a glaſs handle), and let the wire touch the ground. Preſent the cartridge to the knob of a charged jar, and the powder will be fired by the electric ſtream paſſing through it. Tinder, or touchwood, may be ignited by the electric ſtream in that or any other manner. Certainly this fluid muſt be the ſame as fire!

40th. Fix a ſmall ladle in the end of the conductor, and fire a piece of camphor in it: when the machine is excited, the camphor will throw out a variety of ſmall ſhoots, like a vegetable. The inherent electricity of the camphor, having its natural repulſion increaſed by heat, carries off the glutinous reſin in its flight.

41ſt. To perforate glaſs bottles. Fill the vial half full of ſallad oil. Force a ſmall wire through its cork, and bend the end that goes into the bottle, ſo as to approach near the ſide of the bottle, and to be juſt covered with the oil: if on the other end of this wire there be a knob, and that knob held near a charged conductor, ſparks will dart from the conductor to the knob, and at the ſame time from the crooked end of the wire, through the bottle, to the thumb, or any other conducting body preſſed oppoſite to the end of the bent wire. If the wire be turned to other ſides of the bottle, ſeveral ſmall holes may be perforated through the glaſs. Does not this ariſe from the tenacious nature of the oil, which by confining and condenſing the ſpark into a line, or point, enables it to penetrate the glaſs?

42d. To imitate the equal manner in which rain generally falls, put a quantity of braſs duſt, or filings, into a coated jar; and when it is charged, invert it, and throw ſome of the duſt out upon a flat ſurface; the duſt will ſpread itſelf equally upon it like rain or ſnow. Are not both theſe effects from the ſame cauſe, viz. an equal repulſion among the parts?

43d. That the coating of glaſs has little to do with its electric charge, is proved thus:—Lay a plate of tin or braſs on your hand, and on it a plate of glaſs (rather larger than the metallic plate); on the glaſs lay another metallic plate, and let this communicate with the prime conductor: thus the glaſs may be charged. By the edge of the glaſs diſengage it from the two plates, and place two other plates in the ſame ſituation, upon and under the glaſs. If now one knob of the diſcharging rod be made to touch the under plate, and the other knob the upper plate, a diſcharge will enſue the ſame as if the firſt plates had remained in their place.

44th. Metals owe their conducting power to the latent fire they contain. When vitrified, they ceaſe to conduct; when revived, or brought back into a metallic ſtate, they conduct again.

45th. In ſpring, when plants begin to grow, temporary and electric clouds appear, and pour rain in ſmall drops attenuated by electricity. Theſe increaſe in ſummer, as the ſolar ſtream becomes more direct; diffuſing a vivifying ſpirit through the vegetable world, until the fruits are gathered in. This repulſive diſperſion of water by electricity, is beautifully exhibited by hanging a ſmall metallic veſſel of water on the conductor, with a capillary ſyphon in it; the water only *drops* from the ſyphon before it is electrified, but when electrified, the drops divide into numberleſs ſmaller ones, which are luminous in the dark. Steams and vapours alſo conduct electricity; for if the pith balls are ſuſpended four feet above the conductor, they will not part; but if hot water, or a freſh blown-out taper, be placed on the conductor, the balls immediately ſeparate.

Thus have I exhibited this wonderful agent in moſt of the lights in which it has yet been ſeen: and flatter myſelf the reader's deductions from theſe appearances will be ſimilar to my own, viz. that electricity emanates in a perfect ſtate from the ſun and fixed ſtars; that its particles repel each other, and fill all ſpace; that they have an affinity to the earth and planets, but an affinity that cannot eaſily be gratified, becauſe the ſurrounding atmoſpheres are in part non-conductors, being already ſaturated, and, of courſe, repellent of the electric fluid. Hence the ſtruggles which the fluid frequently makes to get through the lower regions of our atmoſphere to the earth, cauſing thunder, lightning, earthquakes, &c.:

for a vacuum *, and the greatly rarefied air, which form the upper ſtratum of the atmoſphere, are conductors, and receive the fluid from the ſun without obſtruction: it then takes poſſeſſion of the clouds, and if the air below be moiſt, that moiſture will conduct it into the earth. But when the lower air is dry, and a non-conductor, it is then obliged to uſe ſtrong efforts, to accumulate in ſuch quantities as are proportionate to the difficulties of its paſſage; it forſakes the clouds with terrible corruſcations; they coaleſce (having loſt that which kept their particles aſunder), and deſcend in heavy ſhowers. As we have ſeen that many terreſtrial ſubſtances, when duly impregnated and united with electricity, become permanent air; may not the atmoſphere itſelf, formed of the finer and more volatile parts of the earth, be made fluid by their union with electricity? May it not be true that the terreſtrial part of the atmoſphere being powerfully attracted by the earth, will, of courſe, be much condenſed near the earth's ſurface, and become more and more rare as we aſcend? May not the well-known effects produced on the human conſtitution, and the appearance of the air juſt before a thunder-ſtorm, be occaſioned by the ſuper-ſaturation of the atmoſphere with electricity? And may not languor, and low ſpirits, in moiſt weather, ariſe from a want of electricity in the air, &c.? For eaſterly winds always induce diſorders, and it is notorious that the air betrays leſs ſigns of electricity in thoſe winds than in any other. Its power of exciting muſcular motion in apparently dead

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* It has been affirmed, that a perfect vacuum will not conduct electricity. I have boiled quickſilver, to expel all its air, in a double or ſyphon, barometer tube, of ten feet in length: when one end of it was inſulated, and communicated with the conductor, the electricity paſſed through it with the utmoſt eaſe; and was luminous in the dark.

animals, as well as of increaſing the growth, invigorating the ſtamina, and reviving diſeaſed vegetation, prove its relationſhip or affinity to the *living principle.* Though, Proteus-like, it eludes our graſp; plays with our curioſity; tempts enquiry by fallacious appearances, and attacks our weakneſs under ſo many perplexing ſubtilties; yet it is impoſſible not to believe it the ſoul of the material world, and the paragon of elements!

LECTURE IX.

OPTICS.

THIS branch of natural philoſophy treats of light, and of the effects produced by its *approach* to, and paſſage *through*, different mediums. But before we treat of theſe effects, it is neceſſary to define what we apprehend light to be. I venture (but with ſome diffidence) to pronounce it DILUTED FIRE. That *attraction* and *repulſion* are the two active agents in inanimate nature, I hope has been ſufficiently proved in the firſt lecture: that attraction is an inherent property in all matter, except fire, and would, if uncontrolled by its repulſive power, make all nature into one ſolid maſs, was alſo, I hope, ſufficiently evident. It ſeems, indeed, neceſſary, in the preſent order and fitneſs of things, that an antagoniſt principle ſhould regulate this coheſive tendency;—and that principle I conceive to be fire. This element exiſts in various forms, and has various names, as active fire, latent heat, ſenſible heat, electricity, lightning, caloric, and laſtly, light. In all thoſe ſtates it loſes not its repulſive power; for even in its latent ſtate, when chemically combined with bodies, and inſcrutable by any of our ſenſes, it gives thoſe bodies elaſticity, and prevents their atoms from forming too cloſe an union. It has been a long-received opinion, that light is but a quality, or property, of fire; but I conceive light to be fire itſelf, originally emanating from the ſun and fixed ſtars, and near thoſe bodies, no doubt, of intenſe heat; but being repulſed radiantly in all directions, it muſt grow more and more dilute; for, that intenſity diminiſhing as the ſquares of the diſtance increaſe, the denſity of ſolar light at the ſun muſt be 45,000 times greater than at the earth: ſo that, at the diſtance of our earth, it becomes only light, united with terreſtrial matter, is evident, becauſe it can be ſtopt, or turned out of its way, in its courſe, by any opaque intervening body. That light is progreſſive, or rather, that it pervades all ſpace, and is only put in motion by the ſun and other luminaries, is, I think, more probable than that its individual particles travel from the ſun to us in about eight minutes, according to general opinion. It is true, we ſee the eclipſes of Jupiter's ſatellites 16′ 24″ ſooner when the earth is in that part of its orbit neareſt to the planet, than when it is in that part the moſt diſtant from the planet; but that does not imply that the individual particles of light fly from Jupiter to our eyes in 16′ 24″: it certainly proves the effect to be progreſſive; for, if we were to conceive a line of particles of light reaching from Jupiter to the eye, and that Jupiter was the agent that put thoſe particles into motion; as thoſe particles are repulſive and elaſtic, the effect of Jupiter's impulſe muſt be progreſſive; it could not be the ſame as if a ſolid rod were to reach from Jupiter to the eye, for then the impreſſion at one end of the rod would be felt at the ſame inſtant at the other.

But as we conceive electricity as the character in which light firſt iſſues from the ſun; and as electricity paſſes through a wire, or any conductor where there is no obſtruction *inviſibly*—May it not paſs from the ſun inviſibly through the conducting vacuum between the earth and ſun; become *light* when it reaches and becomes chemically combined with the terreſtrial particles of air; and *fire* when chemically combined with the groſſer particles of the earth? For when light becomes chemically combined with bodies to which it has a ſtrong affinity, even in, or on the ſurface of the earth, it may be impriſoned, or united by ſo powerful an attraction, that if it is excited and diſengaged by friction, the ſpring of its eſcape may make it become electricity again, and produce thoſe ſurpriſing effects called by that name.

We alſo ſee the fixed ſtars a little different in their ſituation in one part of our orbit to what we do in another: this is called the aberration of light, and may be underſtood by fig. 2, Plate XXXII.; where *a b* repreſents a portion of the earth's orbit, *c* the ſtar. As light is progreſſive, and ſuppoſed to travel from *c* to *b*, while the earth travels from *a* to *b*, the ſtar will be firſt ſeen along the line *a c* (ſuppoſe through a tube): now if a tube be kept parallel to its firſt poſition, when the earth arrives at *e*, the ſtar will be ſeen in the line *e m*; for while the earth travels from *a* to *e*, light has travelled from *c* to *z*; and when the earth arrives at *g*, the ſtar will be ſeen along *g w*;—for the particles of light impelling one another, will have their ſenſible effect at *z*; ſo at *n* it would be ſeen along the line *n o*. Or if *c* was conſidered as a falling drop of rain, juſt entering a tube *a c*, and the tube was kept in the ſame parallel poſition while the perſon who carried it ran from *a* to *n*; the drop, in that time, would fall from *c* to *n*, through the tube, without touching its ſides.

Conceiving from hence that light is progreſſive, emanating from the ſun and fixed ſtars, we may alſo conceive that its particles repel, and fly at a great diſtance from, each other. This may be proved by the eaſe with which the rays of light croſs in the focus of a large lens; or by placing a number of candles in a line before a ſmall hole in a ſheet of paſteboard, when a ſheet of white paper on the contrary ſide of the paſteboard will have as many ſpecks upon it as there are candles; ſhewing that light can iſſue from each candle through a hole made with a pin without the leaſt juſtling or inconvenience. If the particles of light were not, therefore, ſmall beyond all conception, flying with ſuch a velocity, they muſt come into the eye like ſhot out of a gun, inſtead of that imperceptible manner in which they impinge upon the optic nerve. Yet ſmall as they are (and capable of paſſing through tranſparent mediums with little impediment to their motion), their extreme velocity gives them a momentum: for, hang a ſmall ſteel wire by a magnet, and let the focus of a large lens touch the wire, and it will put the wire into motion. A ſmall wire, with a piece of thin copper fixed to one end, was balanced on the point of a fine needle, and encloſed in a glaſs caſe to prevent any motion that might be in the air: the focus of a large concave mirror was then directed upon the piece of copper, which it put immediately into motion, and was computed to have ſtruck it with a force equal to the 1800 millionth part of a grain (according to Mr. Mitchell), on a ſquare foot of the earth's ſurface. This momentum is alſo proved by its tearing in pieces, and diſperſing, the hardeſt and moſt compact bodies, when expoſed in the focus of a large lens. The momentum of common light is not perceived by our ſenſe of feeling, and ſcarcely by ſight; for as the particles move at a great diſtance from one another, the impreſſion of one particle is loſt before another ſucceeds. Yet light coming directly from the ſun, embrowns our ſkin, and inflames and hurts our eyes.

The tail of a comet is obſerved always to point *from* the ſun. Is it not more than probable, that it is the ſtream, or current, of light iſſuing from the ſun that cauſes it thus to point?

Some comets, indeed, have been obſerved to have had the end of the train a little bent. Does not this favour the hypotheſis of light iſſuing from every fixed ſtar as a ſun? That currents of light meet in infinite ſpace, mix, aſſimilate, and unite with one another? That ſtronger currents abſorb, or turn back, the weaker? That the light which miſſes the planets of each ſun is not loſt or waſted, but, aſſembling and mixing with other light, is kept in perpetual motion? That light near each ſun muſt be more denſe than when at a diſtance, and, therefore, that the tail of a comet may be in two currents at once, a ſtronger and a weaker, and thence derive the inflexion at its remoter end?

Light is dormant till put into action by a luminous body, or by heat; ſo in the night the particles of light are ſtagnant (except they are put into motion by the moon, ſtars, meteors, &c. or by candles, or other combuſtibles, in a ſtate of ignition), but aſſume their wonted motion again on the riſing of the ſun. So fire in chemical union with wood, metals, or any combuſtible body, lies dormant, or latent, till forced into action by communicated heat; and coals, wood, candles, &c. will not ignite till they are previouſly heated by a body already in a ſtate of ignition: for fire impels fire, as light impels light; and affords another proof of the identity of light and fire.

The momentum, or moving force, of light being thus eſtabliſhed, and, conſequently, its materiality, let us trace it through different media, and it will be found alſo to have its affinities like all other matter. I admit a ray of light through a hole half an inch in diameter into a dark room: if the air through which it paſſes be of uniform denſity, it proceeds through it in a ſtraight line; but if I let the ray fall obliquely on a poliſhed cube or ſquare of glaſs, as fig. 9, Plate XXXIII. it will be bent towards the centre of the glaſs in its paſſage into, as well as out of it. Does not this prove that light is, in a ſmall degree, the ſlave of attraction, as well as all other matter? If the ray be ſuffered to fall perpendicularly on the glaſs, it paſſes ſtraight through without any inflection; becauſe it is attracted nearly in every direction alike. If the ſame ray ſtrike the inſide of an empty bowl placed on the floor, and the place be marked; it will be found, when water is poured into the bowl, that the ray will not fall on the ſame place, but nearer to that where the ray enters the room. Hence alſo an oar appears crooked in the water. The property which tranſparent mediums have of attracting light out of its rectilinear direction in air, is called refraction, and this effect is in proportion to the denſity or ſpecific gravity of the medium; i. e. water does not bend a ray ſo much as glaſs, nor glaſs ſo much as a diamond, &c. For when light paſſes obliquely into a denſer medium, it is refracted or bent *towards* the perpendicular; when into a rarer, *from* a perpendicular to the ſurface of the medium.

The law of this refraction may be explained by fig. 1, Plate XXXIII. where *b n r* is to repreſent the ſurface of water, and *a n* a ray of light entering the water at *n*, where it will be attracted out of the ſtraight line *a n e*, into the direction *n d*. Now it can evidently be ſeen that the angle of incidence, *a n b*, is greater than the angle of refraction, *c n d*, the ſines of which always bear a proportion to one another; i. e. the ſine of incidence, *a b*, is greater than the ſine of refraction, *d c*, in glaſs, out of air, in the proportion of three to two; out of air into water in that of four to three, &c.

If a ray fall obliquely on a plate of glaſs, or on a body of glaſs whoſe ſides are parallel, with the ſame angle it entered it, with the ſame angle it will leave it on the oppoſite ſide; fig. 9, Plate XXXIII.

From this property are derived the uſe and application of all kinds of optical lenſes; and an explanation of various optical deceptions.

1ſt. I place a cubical box, *s*, fig. 3, Plate XXXIII. in ſuch a direction that I cannot ſee the patch *e*. If a glaſs cube be then put into the box, I ſhall ſee the patch at *a*; *for we ſee every thing in the direction of that line in which the rays approach us laſt.* This is an axiom in Optics, and may be exemplified by placing ſeveral mirrors before a candle, as fig. 4, Plate XXXIII.: though rays iſſue from the candle in every direction, we will take only one, viz. *a b* (to keep the figure ſimple); this ray is reflected to the mirror *c*, from thence to the mirror *d*, from *d* to *e*, and from *e* to the eye *s*. But the mind transferring every object ſeen, along that line in which the rays came to the eye laſt, the reflected lines are put, as it were, to the end of the laſt line, *e s*, and the candle is ſeen at *k*, at the diſtance of all the reflected lines put into one ſtraight one. So the ray *e c*, fig. 3, XXXIII. being refracted in its paſſage out of glaſs into air, into the direction *c r*, the eye perceives it at *a*, nearly one third of the depth of the box from its bottom.

By intuition, or inſtinct, the eye cannot judge of diſtances in air or water, or any tranſparent medium. We learn to diſcriminate diſtances by experience alone. A child will graſp at the moon with the ſame avidity as at a candle within his reach; and a blind perſon brought to ſight, believes every object he ſees to be touching his eyes. Many a ſchool-boy has loſt his life, by ſuppoſing the bottom of a clear river to be within his depth (as the bottom will appear one fourth nearer the ſurface than it really is); and we are worſe judges of diſtances in water, than in air. A fiſh looks larger in water, than when taken out of it. The diſtortion of objects ſeen through a crooked pane of glaſs, in a window, ariſes from its unequal refraction of the rays that paſs through it: and a ſhilling put in the bottom of a punch-bowl, fig. 5, Plate XXXIII. could not be ſeen along the line *a b*; but if the bowl be filled with water, the eye will ſee the ſhilling along the line *a c*. Various and important are the effects of this law, in the order and economy of nature. The ſun is ſeen before he comes to the horizon in a morning, and after he ſinks beneath it in an evening, by the refractive power of the atmoſphere: and hence we never ſee ſun, moon, or ſtars, in the places where they really are; except they are in the zenith, or right over head; in which caſe their light is ſo equally attracted in every horizontal direction, that it paſſes through the atmoſphere without any refraction. This increaſing refraction, from the zenith to the horizon, cauſes much trouble in aſtronomical and nautical calculations, in taking the real altitudes of the heavenly bodies: which may be better underſtood by inſpecting fig. 1, Plate XXXIV. which repreſents half our globe, and its atmoſphere. A perſon ſtanding at *a*, would ſee the ſun riſe at *b*, when it was, in reality, only at *c* (rather more than half a degree beneath the horizon); the line from *d* to *a*, a little bent; becauſe the refractive power of the lower part of the atmoſphere is greater than the upper, the air growing gradually rarer, or more thin, the higher we aſcend in it.

If a perſon at *a*, had the ſun, *e*, in his zenith, he would ſee him where he really is: for his rays coming perpendicularly through the atmoſphere, would be equally attracted in all directions, and therefore ſuffer no inflection. But about two in the afternoon he would ſee him at *i*, though, in reality, he was at *k*, thirty-three ſeconds lower than his apparent ſituation. At about four in the afternoon he would ſee him at *m*, with greater error: for now he is at *n*, one minute and thirty-eight ſeconds from his apparent ſituation. But at ſix o'clock (we will ſuppoſe) he is ſetting, and will then be ſeen at *o*, though he is at that time at *p*, thirty-three minutes below the horizon. Theſe phænomena ariſe from the refractive powers of the atmoſphere, and the obliquity with which the rays fall on it; becauſe we ſee every object we look at along that line in which the rays from it came to us laſt: ſo that I ſee *k* along *a r*; *n*, along *a s*; and *p*, along the line *a t*.

Art has turned the refractive power of glaſs to many important uſes: ſpectacles, though the ſimpleſt, are not wanting in eminence; as they prolong the enjoyment of one of our moſt valuable ſenſes to a date that we ſhould not poſſeſs from nature. They may be made plano-convex, double convex, or concave. The plano-convex lens is plain on one ſide, and a portion of a ſphere, or globe, on the other; ſee No. 1, fig. 2, Plate XXXIV. If parallel rays fall on this lens, they will be ſo refracted in their paſſage through it, as to unite in a focus at *b* (ſee fig. 6, Plate XXXIII.), on the oppoſite ſide of a ſphere, of which the convex ſide of the lens may be conceived as a part. The ray *a b* falling perpendicularly on the lens, and being equally attracted by it, paſſes ſtraight through without refraction.

The double convex lens, No. 2, fig. 2, Plate XXXIV. has double the effect of the laſt, for it aſſembles parallel rays in a focus at the centre of the ſphere of its convexity. The magnifying power of both theſe lenſes depends on this convexity; for the angle of viſion increaſes in proportion as the ſphere of convexity grows leſs. Thus the angle *c d e*, fig. 12, Plate XXXIII. is larger than the angle *n o p*, fig. 8, Plate XXXIII. and would magnify any object ſeen through it more. For every object may be conceived to be big or little, according to the angle it forms in the eye. The pen *c*, fig. 13, Plate XXXIII. would appear to the inexperienced eye as tall as the tree *d*; becauſe it makes as great an angle at the eye: and a ſmall ball held near the eye will cover the ſun. The moon is known to be a mere ſpeck in compariſon of the ſun; yet ſhe appears as large, and can cover his whole diſk in an eclipſe, becauſe ſhe is ſo much nearer to the earth as to form as large an angle at the eye.

In looking at the croſs *a c*, fig. 11, Plate XXXIII. I ſee it under the angle *a d c:* but if I place the lens *b* between my eye and the croſs, the rays which painted the image on my optic nerve before, viz. *a d* and *c d*, will be refracted in the directions *n r* and *o p*; and, of courſe, be uſeleſs to the eye. But the rays *a s* and *c o* falling on the outer part of the lens, will (according to a former explanation) be refracted to the eye in the directions *s d* and *t d*, and form the angle of viſion *s d t*. Hence, as every thing is ſeen along that line in which the rays come to the eye, the top of the croſs will be ſeen along the line *d e*, and the bottom along the line *d m*; conſequently the lens has increaſed the natural angle of viſion *a d c* to *e d m*. In this figure, rays are only taken from the two ends of the object, that it may not be crowded and confuſed with lines; but it muſt be underſtood, that rays iſſue from every part of the object (if it be illumined by the ſun, or a candle), and are magnified equally with the two ends. The magnifying power of ſpectacles, of refracting teleſcopes, microſcopes, &c. depends on this principle.

The ſmall arrow, fig. 15, Plate XXXIII. is repreſented with rays iſſuing from its two ends in all directions; but it is only thoſe rays which fall on the lens *a c* that the lens can effect; the other rays are diſperſed radiantly, and would meet the eye on all ſides: hence the reaſon why bodies can be ſeen on all ſides, either by direct or reflected light. Direct light is that which iſſues immediately from the ſun, or any luminous body; reflected light is that which is rejected or thrown back by poliſhed, white, or light-coloured bodies on the ſides of objects on which direct light cannot fall: and hence the reaſon why parts that are in ſhade are yet viſible. But reflected light (even from an highly-poliſhed metallic mirror) is not quite half ſo vivid as direct light. If the ſmall arrow, fig. 15, Plate XXXIII. be ſtrongly enlightened, a white ſcreen at *d* will exhibit the picture of the arrow enlarged and inverted: for the pencil *a n c* will unite at *r*; and the pencil *a o c* will unite at *s*; and ſo will all the intermediate parts of the arrow. Rays that diverge or ſpread in their approach to a convex lens, will converge proportionally to a focus beyond it: ſolar rays may be conſidered as parallel, and converge beyond the lens to the *real* focus, as at *a*, fig. 8, Plate XXXIII.

Hence an eye placed at *u*, or ſtill nearer the lens, fig. 15, Plate XXXIII. would ſee the ſmall arrow upright; but placed at *d*, the dart would appear to be inverted on the retina, or optic nerve, as on the ſcreen *r s*. For all objects of ſight, duly enlightened, have their pictures painted on the optic nerve, when the eye is turned to them, as on the ſcreen *r s*; from which picture we learn to judge of the length, breadth, ſhape, colour, &c. of all objects we look at.

Not only on the retina, or optic nerve of the eye, are objects painted inverted, for a convex lens produces the ſame effect on a ſheet of paper held in its focus, as *e r*, fig. 3, Plate XXXIV. The croſs *a b* is ſuppoſed to be ſufficiently illumined to puſh its light through the lens *c d*; but we ſhall only take a pencil from *a*, and another from *b*, that the figure be not confuſed with lines. The ray *a c* becomes influenced by the attraction of the lens, and, agreeably to the laws of refraction (already explained), is drawn towards the centre of the lens, into the direction *c r*. Could the ray *a c* have gone forward to *e*, the croſs would have been pictured upright; but to have done this, Nature muſt have invented a new law, different from every attraction we meet with in her works. For all attractions are towards the maſs, or centre, of bodies: of courſe the lens, attracting towards its centre, inflects the ray *a c* in the direction *c r*; and the ray *b d* in the direction *d e*. So that the pencil *a c d* unites at *r*, and the pencil *b c d* at *e*; and ſo does the light from every other part of the croſs, and, of courſe, the whole picture is inverted.

Rays being ſuppoſed to come parallel from the ſun, or any very diſtant object; a convex lens, held perpendicularly to ſuch light, will unite it in its real focus: for converging rays will throw that focus farther, and diverging rays nearer. In fig. 14, Plate XXXIII. the parallel rays *a a* come to a focus at *c*. The diverging rays *b b* unite at *d*, and the converging rays *s s* unite at *g*. So when objects are near the lens, their pictures on an oppoſite ſcreen will be large; but the pictures will grow leſs, as the object removes from the lens: fig. 5, Plate XXXIV. The object *a* produces the picture A; the object *b* produces B; and the ſame object at *c* produces C, &c. When convex lenſes are very large, their focus produces on opaque bodies the moſt intenſe heat producible by art. One of three feet diameter (having its focus condenſed by another ſmaller lens) fuſed twenty grains of gold in four ſeconds; twenty grains of ſilver in three ſeconds; ten grains of platina in three ſeconds; ten grains of caſt-iron in three ſeconds; a topaz of three grains in forty-five ſeconds; cryſtal pebble, ſeven grains, in ſix ſeconds; flint, ten grains, in thirty ſeconds, &c.

Lenſes, therefore, for optical purpoſes are (fig. 2, Plate XXXIV.): No. 1, plano-convex; 2, double convex; 3, plano-concave; 4, double concave; 5, meniſcus; 6, the priſm. For the ſame reaſon that a convex lens increaſes the angle of viſion, and magnifies objects, the concave lens diminiſhes them. For the thick part of this lens, fig. 2, Plate XXXIV. No. 3 and 4, is on its outſide; therefore its attractive and refractive powers are not, as in the convex lens, tending towards a centre, but towards a circumference. Hence the concave lens diſperſes the rays, or ſpreads them out radiantly: perfectly agreeing with the forementioned laws of refraction, by the obliquity with which they fall on the glaſs. Hence alſo their diminiſhing power. For if *a b*, fig. 4, Plate XXXIV. repreſent an arrow ſeen by the eye along the lines *c a* and *d b*, and if then I interpoſe the concave lens D between my eye and the object, the line *a c* will be bent towards *g*, and the line *b d* bent towards *k*, and, of courſe, both become uſeleſs to the eye. But the ray *a o*, ſuffering a ſimilar refraction, will be bent towards the eye in the line *o c*; and the ray *b r* will be ſent to the eye in the direction *r d*. Now as every point of an object is ſeen along that line in which the ray approaches to the eye laſt, the point of the arrow is ſeen along the line *c o* at *n*; and the hilt of the arrow along the line *d r* at *m*, diminiſhed and diſtant.

The meniſcus glaſs is like the cryſtal of a common watch. It neither magnifies nor diminiſhes objects ſeen through it: except its inner and outward ſurfaces are portions of different ſpheres.

The focal length of any convex lens is eaſily found, by holding its axis in a line to the ſun: the burning point, or the ſmalleſt ſpeck, is its focus; the diſtance of that focus from the lens is its focal length.

The ſize of an image may be increaſed at pleaſure by bringing the object nearer the focus of the convex lens.

When the eye and an object are fixt, if a concave lens move from one to the other, the ſize of the object will increaſe to the middle, and then decreaſe again.

The brightneſs of an image increaſes with the ſize of a convex lens, but decreaſes in diſtinctneſs; for only the rays which fall on the central part of the lens converge to a point; thoſe towards the edge diſperſe as in a priſm, and make the object confuſed. Hence the lens of the eye is all covered by the iris, except its centre; and reading-glaſſes have their edges ground off, or covered with black horn: this defect is called the aberration of ſphericity.

When rays of light paſs near to any body, ſo as to come within the ſphere of its attraction, or repulſion, a partial refraction, or reflection, takes place: all the colours being bent either *towards* or *from* the body; but ſome more than others, though at the ſame diſtance: ſo that coloured ſtreaks appear both within the ſhadow and on the outſide of it; the neareſt is inflected moſt. If *n*, fig. 6, Plate XXXIV. be a hair croſſing a ray of light, little wider than itſelf, it will repel the neareſt *a c* and *a b* to the greateſt diſtance; and if the edges of two knives approach each other, a ray paſſing between them through a hole, made with a pin, in ſheet-lead, this repulſive power will be ſtill more evidently ſeen.

But of all optical lenſes, the priſm is the moſt important and inſtructive; by this triangular piece of glaſs are we enabled to analyze a ray of light, and account for the cauſe of colours. If a ray be let through a hole, of half an inch diameter, into a room lined with black cloth, and perfectly impervious to all light, except what paſſes through the hole, and a priſm interſect it as *a*, fig. 9, Plate XXXIV. the ray will ceaſe to go forward in the direction *c d*; it will be decompoſed, and exhibit on a white ſcreen a beautiful ſpectrum, conſiſting of ſeven primitive colours, viz. red, orange, yellow, green, blue, indigo, and violet. The edges of the adjoining colours ſeem to melt into, or mix with one another; which makes the line of diſtinction between one colour and another not well defined, except the experiment be made with great accuracy. This definition of limits was, however, effected by Sir Iſaac Newton; in which he found that the width of each colour was agreeable to theſe numbers, viz. red 11, orange 8, yellow 14, green 17, blue 17, indigo 11, and violet 22. This is ſuppoſing the length of the ſpectrum of colours to be divided into 100 parts. Fig. 11, Plate XXXIV. will more particularly explain this. If the priſm be held perpendicularly to the ray, and turned, the ſpectrum will be ſeen to riſe above and fall below a place where it will ſeem inclined to ſtop; when fixed at that place, the ſpectrum will be perfect, and if meaſured, and divided into 100 parts, each part will bear a proportion to another, as the ſpectrum *a b*, fig. 11, Plate XXXIV. which intervals anſwer to the intervals of the diatonic ſcale of muſic; i. e. if A L be a muſical ſtring divided into two equal parts, the half A A will be an octave to the whole ſtring; and if that half be divided into 100 parts, twenty-two of thoſe parts will make the interval between A and B, and anſwer to the breadth of the violet colour. Eleven of the ſame parts will make the interval between B and C, &c. &c. Theſe intervals may alſo be repreſented by the aliquot parts of the ſtring A L; viz. A. B is eight ninths of its length, and forms the boundary of the violet colour; A C makes five ſixths of its length, making the limit of the indigo; A D is three fourths of the line A L, and forms the diviſion between the blue and green colours, &c.

This wonderful conformity between muſical notes, and the refrangibility of light, ſeems as if our ſcale in the major key had its foundation in nature. The analogy is double: there are but ſeven notes in muſic, excluſive of interpoſing ſemitones; and there are only ſeven primitive colours in nature; and theſe colours ſuffer a refraction in their paſſage through the priſm, that marks the proportional diſtance at which a performer ſhould place his fingers on the finger-board of his violin.

This varied refrangibility we apprehend ariſes from the difference of ſize, or denſity, in the particles of light. We find the red part of light capable of ſtruggling through thick and reſiſting mediums, when all the other colours are ſtopt. The ſun, therefore, appears red when ſeen through a fog. Diſtant light, even tranſmitted through blue or green glaſs, always appears red; and lamps at a diſtance, ſeen through the ſmoke of a long ſtreet, are red, while thoſe that are near, are white. Dr. Halley's hand appeared red, in the water, when he was in a divers'-bell, at the bottom of the ſea. This colour always makes the ſtrongeſt impreſſion on the eye; and a blind man imagined it to be like the ſound of a trumpet. Are not theſe proofs that red light conſiſts of the largeſt ſized particles of light; which, therefore, have a momentum, capable of puſhing through ſuch reſiſting mediums as ſtop, or abſorb, the reſt? accordingly, the red part of light, in paſſing through the priſm, is the leaſt refrangible of any other; and the violet the moſt, as probably conſiſting of the ſmalleſt ſized particles. If any colour be ſeparated from the ſpectrum by another priſm, it will not change, but retain its colour; which ſhews that the colour is in the ray of light, and not in the bodies on which the colour falls. If the red ray be ſeparated, as fig. 1, Plate XXXV. and made to fall on a blue cloth, it will ſtill be red, though the blue may mix a little with it. So if the priſm be raiſed through the orange, yellow, green, &c. in ſucceſſion, the colours will ſtill be orange, yellow, green, &c. ſhewing that the colour on any body is not the colour of that body, but of the rays it reflects. Why is my coat black? becauſe that hue has ſo ſtrong a chemical affinity to light, univerſally, that it abſorbs the greateſt part of the light that falls upon it, and reflecting little, makes a blank on the nerve of the eye, and we call it black.

In transferring fire from one body to another, heat is always produced (vide Chemiſtry); ſo black cloth expoſed to the ſun imbibes his rays with ſo ſtrong an affinity, that, to a wearer, it is warmer in winter, and hotter in ſummer, than cloth of any other colour. A piece of black and a piece of white marble, laid on ſnow in the ſun, demonſtrates this: for the black marble will become hot, and melt the ſnow; while the white marble, rejecting, or throwing off, all the rays of light, receives little or no heat. Hence we ſay, that neither black nor white are colours; for the firſt abſorbs all, and the ſecond rejects all. And hence the coolneſs of white muſlins, and their propriety as ſummer clothing.

That heat ſhould be produced by the abſorption of the rays of light that fall on the black body, is ſtrongly in favour of light having a chemical affinity to certain bodies, and chemical rejection to others. It unites with avidity with black bodies, and flies from white. May not the colour of all bodies ariſe, therefore, from this chemical affinity, and this chemical rejection? It is true, black bodies can be ſeen, though they are conſidered as abſorbing all the light that falls upon them; for ſome light will be reflected from the outſide fibres, or inequalities of the body; and the quick abſorption of ſuch bodies, and the vibrations made among their particles, by that abſorption, will occaſion heat, till the union is perfected. And when ſuch bodies are heated, ſo as to be diſpoſed to let go their latent light in the character of flame, if they are not black, they univerſally turn ſo, before they ignite into flame. This paper is white, yet very combuſtible: we muſt not ſuppoſe that it rejects *all* the rays that fall upon it, any more than that black abſorbs all; enough will be retained to give it ignition, when air (the other ingredient of inflammability) has ſuch convenient acceſs to its ſingle leaves. But a quire of it, made compact (as in Clay's manufactory), will burn no better than a ſtone. Is not flame, therefore, ſolar light let looſe by combuſtion? and is not the colour of bodies a diſpoſition in them to abſorb ſome of the ſeven primitive colours, and reject others? Why is this cloth green? Is there any thing inconſiſtent with the known laws of nature, in conceiving, that it abſorbs the red, the orange, the yellow, the blue and violet, and reflects the green, which, meeting the eye, impreſſes that colour upon the optic nerve? Why is the ſun ſaid to deſtroy the colours of cotton, linen, ſilk, &c.? Is it not cauſed by chemical affinity, or chemical rejection? May it not be, that the cloth having a ſtronger attraction to ſome of the coloured rays, than to the colours with which the ignorant dyer has impregnated his cloth, it rejects the dye; and ſtriving to receive the colour intended by nature, confounds both? We are taught by an ingenious experimenter, that we ſee colours by tranſmitted, not by reflected light: that light firſt paſſes through the colouring particles, on the ſurface of bodies; that it there meets with a white ſurface, which reflects it back again, through the colouring particles, and that ſo tinctured it comes to the eye. Some nice obſervations are made, that a fibre of green wool, cotton, or ſilk, is white underneath this coat of colour. But how this can be proved, or why light ſhould be at the trouble of penetrating the hard ſurface of a piece of yellow marble *twice*, I leave to thoſe minute philoſophers, who amuſe themſelves with puerile ſubtilties. It is an excellent rule in philoſophiſing, not to admit of more cauſes than will account for the phænomena. Why may not light have its affinities, as well as the more groſs bodies of the chemiſts? Do not all metals abſorb it? Are not the oxyds, or calces of metals, revived by it?

In a dark room, lined with black cloth, if there be a contrivance by which a hand may be put out into the light, without letting light in, theſe experiments may be made:—Put a letter into the light, and keep it expoſed to it about a minute; when it is drawn into the dark room, it will be as viſible as the paper you now read from; but it will inſtantly begin to emit, or repel, the light, and grow darker and darker, till it becomes as inviſible as any thing in the room.

2d. Lay a key on the letter, and put both into the light as before. When they are drawn into the room, the paper will be luminous as before; but the key will be quite inviſible, and if taken off the paper, will leave its ſhape upon it, as if marked with ink. Are not the abſorption of light by the metal, and the rejection of it by the white paper, made viſible by theſe experiments? Light may be forced out of iron priſmatically, by gradually increaſing heat. Lay a thin ſlip of iron on a red-hot plate of the ſame metal; the ſlip will firſt turn of a violet colour; as it becomes hotter it will turn blue; hotter ſtill, and it will aſſume a greeniſh-yellow hue: if the heat increaſe it becomes red; but if that heat be made intenſe, all the rays of light are forced out at once, and it becomes a white heat as workmen call it; for the mixture of the ſeven primitive rays together, univerſally produces a white. Steel is frequently heated to the blue colour, and there ſtopt; hence we have blue ſteel trinkets, tools, furniture, &c. for the ſurface of the ſteel at that heat acquires a diſpoſition not only to emit blue light, but to have that diſpoſition fixt by cooling, ſo as to reflect blue light long after.

That iron is capable of ſuperſaturating itſelf with light, is evident from the copious manner in which it emits it, when burnt in vital air. For if a piece of ſmall iron wire, or a watch-ſpring, have a piece of tinder lighted on its end, and then be plunged into a quart of vital air, the metal will burn with a white light too intenſe for the eye to look at. (Vide Chemiſtry.)

That light enters into the texture of bodies, and becomes a conſtituent part of them, all nature demonſtrates. How elſe are we to conceive that the quantity of light poured on the earth by the ſun, ſince the creation, has been diſpoſed of? That light is but fire in a greatly diluted or rarefied ſtate, is proved by condenſing it by a large lens, or concave mirror; the focus of which ignites combuſtible bodies, melts the hardeſt metals, and vitrifies bricks, ſtones, &c. and this, independently of air; for the ſame effects take place in vacuo. Even by its natural condenſation in the character of lightning, it produces the ſame effects: and foreſts, in the torrid zone, have been ſet on fire by the ſun's direct rays, without either natural or artificial condenſation. Can we, therefore, doubt, *That all fire is originally derived from the ſun?* By the repulſive energy of fire, the ſolar atoms are impelled through ſpace; and more particularly through that part of ſpace which ſurrounds the plane of the ſun's equator. For as the ſun revolves on his axis in about twenty-five of our days, it is natural to ſuppoſe that the centrifugal velocity of his equatorial parts muſt give additional velocity to the particles thrown off from thence; and diffuſe them through the zodiac (or that ſpace through which the earth and planets revolve) with a force that may, perhaps, be one cauſe of both the annual and diurnal motion of the planets. (But of this hereafter.) Though a greater quantity of light may thus be thrown off, and diffuſed through the immediate track of the planets, than can impinge upon them; ſo that much of that light muſt miſs them, and fly ſeemingly waſte through infinite ſpace; yet, as we find the fixed ſtars turn on their axes, in like manner as our ſun;—that their light comes progreſſively to us like the ſun's light; and that they have many other attributes in common with our ſun;—can we doubt that they are ſuns themſelves, diffuſing light around them, and giving vegetation to various worlds? How grand is the idea of light iſſuing from thouſands of ſuns; and meeting in different directions without juſtling or impediment! (for by mirrors we can make portions of ſolar light meet one another in every direction, without cauſing the leaſt obſtruction.) We may ſee hence that light is not loſt or waſted; that it may travel from one ſun to another, and that in all directions; or meeting with more powerful light, may be abſorbed into its motion, and turned into a contrary direction to that in which it was originally projected. For, from the manner in which the ſun's rays put out a common fire, we ſee how the greater momentum of ſolar light will overcome and turn back the weaker rays of culinary light *: and by placing twenty candles in a row, before a ſmall hole in a ſheet of paſteboard, twenty ſpecks will be made on a ſheet of paper on the oppoſite ſide; ſhewing that the particles of light fly at a great diſtance from each other, and, therefore, croſs one another without juſtling or inconvenience. Need we be ſurpriſed that we perceive no waſte in the ſun? that his ſize is not diminiſhed? or, that his light and heat have loſt nothing of their original energy? For the ſmall quantity of light abſorbed by the planets, can rob him of little; and even this light is perpetually let looſe, and thrown back into the general maſs of light, by combuſtion, excited electricity, volcanoes, &c.

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* See vol. I. page 3.

It is a known fact, that all lands riſe above their former common level by cultivation ; for, by looſening their texture, it gives freer admiſſion to light and air ; and how neceſſary light is to vegetation, is too well known to be enlarged upon : vegetables conſiſt principally of light ; which, by affinity, becomes incorporated with the earth, air, and water, which form the other parts. For when vegetables are decompoſed by combuſtion, we find that the quantity of earth, water, or air, contained in them, is inconſiderable when compared to the bulk of the plants. It follows that the light let looſe by the combuſtion, formed the greateſt part of their maſs. Though vegetables may ſeem to rot on the ſurface of the earth, they ſtill retain much of their latent light : they raiſe the ſurface, where they rot, above its uſual level ; and render much of that ſurface combuſtible. Nay, though thoſe vegetables become animal food, and depoſit a portion of their latent fire in the ſtomach, a large portion of it returns to the earth, and contributes to raiſe its ſurface, and render that ſurface combuſtible.

Hence the general ſurface of the earth, as well as its vegetable produce, is univerſally combuſtible, or impregnated with ſolar light, which lies in a latent and inſenſible ſtate ; but which may be called into an active and ſenſible ſtate by combuſtion, fermentation, friction, or ſtrong affinities.

Trees, moſs, turf, and even the earth's ſurface itſelf, are combuſtible to the depth of a few inches ; below which it may be ignited, or made red-hot, by heat, but not to emit flame, or ſolar light. Pit-coal may ſeem an exception ; for it is got many fathoms below the ſurface. If we fill a retort with bruiſed coal, and diſtil it in the uſual way, there firſt comes over a little phlegm, or water, of an acid ſmell and taſte; then a kind of oil, like turpentine; after which a thick tar: and a black coal remains behind. Fill a ſimilar retort with ſaw-duſt, or wood to be charred in iron retorts, and the ſame ingredients will be produced. May not pit-coal, therefore, be antediluvian foreſts, turf-moſs, and the fat of fiſh, covered by earth in the general deluge? and in burning this foſſil, may we not let out light that has been impriſoned five thouſand years? This is not a jeſt. Light may be impriſoned (as every one knows) for hundreds of years in dry wood; and when developed, or let looſe by combuſtion, may blaze more vividly than when cut down: becauſe, when growing, it was united with much water; and water, both in its natural and gaſſeous ſtate, has been ſhewn to have a peculiar affinity to ſolar light, to carry it into, and retain it in, a latent ſtate.

As the earth's ſurface riſes by agriculture, or by being opened to the ſun; and thence, has its capacity for receiving ſolar fire increaſed; may not ground thus riſing, and becoming more and more impregnated with the eſſence of fire, have a progreſſive tendency to ſpontaneous ignition? When cultivation therefore becomes univerſal, by increaſed population, and the earth's ſurface becomes deeper and deeper impregnated with the principles of inflammability (for putrified or rotten vegetable or animal ſubſtances, which increaſe the earth's ſurface, do not loſe *entirely* their inflammable principle, only a part of it is diſſipated in their decompoſition), may it not come to paſs, what has long been conſidered as a prophetical idea, "That the World was to be deſtroyed by Fire?"

In the proceſs of charring wood, it muſt be obſerved, that a heap of wood is covered up under a coat of turf, and then ignited; air-holes are made through the turf, to let in juſt ſo much air as may keep alive the ignition, without ſuffering it to blaze out. This being kept up for eight or ten days, the light inherent in the wood becomes concentrated and fixed in the calx of the wood. Or, if wood be roaſted in a cloſe iron veſſel, with apertures for letting out a vapour of water and an acid, fire is ſtill better concentrated. Bergman proves, that 99 parts out of 100 in charcoal, are of the inflammable principle, or what I call fire. Now, neither fire nor any inflammable principle can be proved to be anywiſe concerned in the growth of wood, *except light be diluted fire*: light in combuſtion is let out from charcoal in ſuch abundance, that but the one hundreth part of an aſh or earth remains.

Dryneſs in the air is exhibited by thoſe plants that have large and thin leaves, ſuch as the gourd, the beet, the petaſite in the fields, and the cacalia in the mountains:—they droop and incline on the approach of dry and ſtormy weather; but aſſume an appearance of vigour when the dews and rain have reſtored elaſticity to their fibres: ſo that the dry air, relaxing and emptying their veſſels, gives them the power of abſorbing the carbonic rain-water that ſucceeds.

Air, as before obſerved, is neceſſary to inflammation. No flame can take place, or exiſt, without the vital part of air. Why?—The air near the earth is mixed with terreſtrial particles, which arreſt ſolar fire in its paſſage through it (for air, water, glaſs, &c. that are *really* tranſparent, ſuffer light to paſs through them, even in its moſt condenſed ſtate, without imparting any heat to them). The lower part of the atmoſphere, therefore, being leſs tranſparent, arreſting a portion of light or fire in its paſſage through it, and that light being alſo heated by reflected light from the earth's ſurface, they together aſſiſt the ignition of combuſtible bodies, to a certain height in the atmoſphere. For rarefied air will not ſupport flame; and, therefore, as the atmoſphere grows gradually thinner as we aſcend in it, there muſt be a height where flame could not exiſt. This, however, muſt be at a great elevation, becauſe we have ſeen fiery meteors at the height of many miles. Perfectly tranſparent air being thus incapable of receiving heat from ſolar light, it is the opaque earth that gives heat to the lower regions of the atmoſphere; and hence the increaſing coldneſs as we aſcend in it.

Perhaps it is the conflict between incident and reflected light, that aſſiſts in giving heat to the earth's ſurface, and the air in contact with it; for rays made to croſs one another, always produce additional heat at the place of their meeting. The variety of ſmooth ſurfaces among ſtones and pebbles by which light is reflected; the chemical rejection of ſome bodies to light, by which it is thrown back; and the bending, or refraction, which light ſuffers in paſſing through tranſparent ſubſtances; muſt mix and compound the rays in ſuch a variety and multitude of focuſes, as to give great heat to the earth's ſurface, and the air in contact with it. This is powerfully exemplified among mountains on a hot day, where their ſeveral ſides reflect light to one place: in that place the heat is intolerably ſcorching! The ſandy deſerts of Barbary afford another proof, as well as the rocks and ſands of all other countries.

The inſtinctive tendency which all living vegetables have towards light, ſhews how much it is neceſſary to their very exiſtence. Cloſe-wooded trees have only leaves on their outſides next to the light, as cedars, laurels, bays, pines, box, &c.; and where a tree is incumbered with others on one ſide, it will grow buſhy and luxuriant on the other: trees planted too cloſe, grow very ſtraight, very tall, buſhy at top, and elſewhere without branches; always puſhing towards the ſun, or tending towards light. Geraniums, growing in a window, turn their flowers towards the light, even near a fire: and plants, growing in the dark, will find a hole (if there be one) through which they will puſh into the light; but if they are doomed to darkneſs, they turn pale, and die, as is the caſe with blanched lettuce and other vegetables. It is much the ſame with land animals: horſes, dogs, ſheep, cattle, &c. pine away, when long confined in darkneſs: and in the human ſpecies, miners, weavers, priſoners, &c. are always pale and ſickly; and, indeed, all whoſe profeſſions are carried on within doors. Owls, and inſects that fly by night, are of a whitiſh colour; ſo are grubs and worms. As vegetables become blanched and colourleſs when ſhut out or covered from the light, it follows, that the colour of leaves and flowers is derived from light. Why is graſs green? Is it not that the organization of plants diſpoſes them to unite chemically with all the rays which fall upon them, except the green part of that light, which they chemically reject, and throw off in all directions; ſo that when thoſe meet the eye, a green colour is impreſſed or painted on the retina, or optic nerve? As light is an aſſemblage of ſeven different ſized particles, and theſe of different colours, viz. red, orange, yellow, green, blue, indigo, and violet, as ſhewn by the priſm, is it not agreeable to the ſame analogy, that differently organized flowers ſhould have different affinities, ſome rejecting one colour, and ſome another; nay, that one and the ſame leaf of a flower ſhall, in parts, be of ſo different a texture, as to reflect red, blue, violet, &c. light? The tricoloured violet, or heart's-eaſe flower, has one part of each leaf yellow, and another violet. Examining theſe with the deeper magnifying powers of a microſcope, in a ſtrong light, it will be found that the texture of the yellow and violet parts is very different. In like manner, the red and white roſes will be found to differ in their texture: and that flowers of the ſame colour, but of different kinds, will be found to have a ſimilar texture. The feathers of the butterfly's wing may be ſeen, by a deep magnifier, to be of different ſhape and contexture in their different colours, &c. &c. Is it not, therefore, a diſpoſition in the ſurface of bodies to reject this or that coloured light, by which they may be ſaid to be of this or that colour? and do not all paints or dyes merely qualify the ſurfaces of bodies to reject this or that coloured light? That reflection is occaſioned by a repulſion taking place at ſome diſtance from the ſurface of the reflecting body, no way militates againſt this doctrine; for fire or light is the very principle of repulſion, and no doubt acts, or has an influence, at a diſtance from the ſurface of bodies, particularly when warm. Sir Iſaac Newton ſeems to have entertained a ſimilar idea, in the query, where he ſays, "Are not groſs bodies and light convertible into one another? and may not bodies receive much of their activity from the particles of light that enter into their compoſition?" May we not, therefore, conceive that plants and trees derive their different colours from the affinities and rejections they have to particular coloured light? That the indigo leaves abſorb blue light; the lignum nephriticum red light: and that infuſions of theſe woods only ſuffer blue and red light to paſs through them? For, take a ſquare bottle filled with a red tranſparent liquor, and another of the ſame ſhape filled with a blue tranſparent liquor, and hold them up before the light, and nothing can be ſeen through them: for the red bottle ſtops the blue light; and the blue bottle ſtops the red light; ſo that the two held together become as opaque as a piece of coal. If a growing red roſe be placed near, and in the light of, a decanter filled with a blue tranſparent liquor, and the decanter juſt fill a hole in the ſhutter of a dark room, the roſe in a few days will acquire a bluiſh tint.

Many tranſparent mediums reflect one colour, and tranſmit another, as is the caſe with the infuſion of lignum nephriticum, which ſuffers the red light to paſs through it, and rejects the green. So, leaf-gold held before the light is green; by reflected light, yellow.

It is more than probable, that in hot climates (or in hot weather in our own), vegetables become ſuperſaturated with light, and emit a portion of it; for heat increaſes its repulſive property: but in this radiant emanation, a quantity of the eſſential oil of the plant will be carried off along with it, and produce thoſe aromatic odours, ſo agreeable to the ſenſe of ſmelling.

This is ſtrongly exemplified in pieces of odoriferous bodies floating on water: the emanation is ſo ſtrong, that from the reaction of the water, the pieces will whirl round as if they were alive. Thin pieces of camphor will always be curled up when ſhaved off by a knife; and falling on water, will only touch it in one part; for the oilineſs of the gum, and its lightneſs, will make it repel the water, ſo as ſcarcely to touch it. From the parts of the camphor elevated above the water, the odoriferous ſtream is ſo ſtrong, that, puſhing againſt the water, it is put into a circular motion, which will continue for ſome hours, if the ſurface of the water be kept clean, by laying filtering paper upon it; but the ſmalleſt drop of oil ſtops the motion in an inſtant.

The reſins and volatile oil of plants are conceived to be derived from light. Some plants contain this ſtrong ſmelling matter in their young branches; ſome in their leaves and buds; ſome in the calyx of their flowers; and ſome in their barks. But without light, neither colour, taſte, ſmell, combuſtibility, growth, flavour of fruit, or this reſinous principle, would have any exiſtence! Hence it is, that, in hot climates, where light is more pure, reſinous or aromatic ſubſtances more particularly abound. Light alſo qualifies plants to emit vital air: for freſh leaves put into an inverted glaſs veſſel full of water, will produce a pint of this air in a few days, if expoſed to the ſun's light. It diſengages vital air alſo from the nitric acid, the oxygenated muriatic acid, &c. &c. and reduces the oxyds or calces of gold, ſilver, copper, lead, &c. to their metallic or reguline ſtate.

"Organization, ſenſation, ſpontaneous motion, and life, exiſt only at the ſurface of the earth, and in places expoſed to the light." We might affirm "that the flame of Prometheus's torch was the expreſſion of a philoſophical truth which did not eſcape the ancients. Without light, nature would be lifeleſs. A benevolent God, by producing light, has ſpread organization, ſenſation, and thought, over the ſurface of the earth." *Lavoiſeur.*

But to return to the refrangibility of light in the priſm, drops of rain, &c. It is certainly evident, from former experiments, that the refrangibility of different coloured light bears an invariable proportion to the ſize of it particles: i. e. that the red part of light, conſiſting of the largeſt ſize, has therefore the greateſt momentum (or moving force), and, of courſe, is the leaſt liable to be turned out of its way by the priſm, or any other attracting medium; that the orange is the next in ſize and refrangibility; and ſo on to the violet, which conſiſts of the ſmalleſt ſized particles, and is, therefore, the moſt turned out of its direction. In other words, the refrangibility is inverſely as the ſize of the particles. That theſe colours are inherent in their different ſized particles, and incapable of being changed into any other, will be proved by fig. 4, Plate XXXV.; where a ray of light is intercepted by the priſm *n*, and throws the colours on the black ſcreen *m*, in which there is a ſmall hole, *a*, that will admit the green part of the ſpectrum to paſs through. If that green ray be received by the priſm *o*, it will be green on the ſcreen *e*: if that ſcreen was of wood, ſtone, or metal, of any colour whatever; or if *e* was a mirror, and reflected the ray to *d*; ſtill the green colour would remain unchanged and unchangeable. If the hole in the ſcreen *m* was ſhifted, ſo as to receive the red, the blue, or any other part of the ſpectrum, it would be found that neither refraction nor reflection would alter the colour. Colour, therefore, is eſſentially in the rays of light, and not in the bodies that either reflect or refract them. Now, if the lens *b c* be held perpendicularly to the diverging priſmatic rays, they will be brought to a focus at *g*, and that focus will be white; ſhewing that the mixture of the ſeven colours together produces a white. If oil colours on a pallet were mixt together in the proportions as fig. 11, Plate XXXIV. viz. violet as 22, indigo as 11, blue as 17, green 17, yellow 14, orange 8, and red 11, they would produce white. So if a circle, fig. 7, Plate XXXIV. was painted in its compartments, agreeably to the diviſions, fig. 11, Plate XXXIV. viz. 22, 11, 17, 17, 23, 8, 24, and put into a ſwift circular motion, the whole circle would, in ſtrong light, appear white; for its colours would, by that motion, be mixt as on a painter's pallet.

Why, therefore, is this paper white?—Becauſe it reflects the reateſt part of all the rays that fall upon it. Why is ſnow white?—Every flake of ſnow being but an aſſemblage of frozen globules of water ſticking together, it reflects and refracts the light that falls upon it in innumerable directions, ſo as to mix it as intimately together as in the whirling ſpectrum; and, of neceſſity, to produce a white image in the eye. A caſcade is white for the ſame reaſon.

Many contend that there are but three primitive colours, viz. red, blue, and yellow, becauſe out of theſe three can be made (by mixture) all the ſeven; for any colour may be produced by mixing the two immediate contiguous colours in the priſmatic circle, fig. 7, Plate XXXIV. Suppoſe I wiſh to make a violet by mixture; indigo is on the right, and red on the left of that colour, in the circle; theſe mixed in the proportion as in the circle will produce the colour. Now as red occupies 11 parts in the circle, and indigo 11 parts, equal quantities of theſe colours mixed on a pallet will produce violet. Or, if a circle, fig. 8, No. 1, Plate XXXIV. be painted one half red and the other indigo, and whirled round, the colour of the circle will be violet.

Blue and yellow produce green with this proportion, viz.
Blue occupies a ſpace of 17 in the circular ſpectrum, fig. 8, No. 2, [Plate XXXIV.
Yellow - - 14
Of the 100 parts - 31 is the proportional ſpace for blue and yellow. So, as 31 is to 100, ſo is 17 to 55 nearly;
and as 31 : 100, : : 14 : 45.
A circle, therefore, No. 2, divided, ſo that 55 parts of it were

blue, and 45 parts yellow, its ſwift circulation would produce a green. In like manner, green and orange produce yellow. Yellow and red, orange, &c.

Theſe three colours have ſtill a further claim to being primitive, as their proportional mixture, like that of the ſeven, produces white.

Red occupies 11 of the 100 parts in the priſmatic circle, fig. 7,
[Plate XXXIV.
Blue - 17
Yellow - 14
So, as 42 is to 100 parts, ſo is 11 to 26, for red;
as 42 : 100 : : 17 : 40.4 for blue;
as 42 : 100 : : 14 : 33.3 for yellow:
100 nearly.

If, therefore, a circle be formed of 100 parts, and 26 parts be coloured red; 40.4 parts, blue; and 33.3 parts, yellow; as fig. 8, No. 3, Plate XXXIV.; the circle when put in motion will be white.

But though a violet may be produced by blending red and indigo; a green, by blending blue and yellow; and an orange, by blending yellow and red; yet the violet, green, and orange, ſo produced, are compounds, and not like the real priſmatic colours; for let them be paſſed through a ſecond priſm, and they become decompoſed into their original or elementary colours.

Any three adjoining colours in the ſpectrum, when combined, produce the middle colour; the proportions found as above:

Red - 25
Violet 50 } This union produces violet, &c.
Indigo 25
100

Any four adjoining colours in the ſpectrum, when united in their due proportions as above, a tint intermediate to the ſecond and third colours will be produced. For the firſt and third produce the ſecond, which is intermediate; and the ſecond and fourth produce the third, which is intermediate to them; conſequently the tint produced by all four will be the ſame as would have been produced by combining the ſecond and third, or the two intermediate colours. Hence the effect of theſe combinations is the ſame as in the primitive colours, i. e.

Violet = 22, and blue = 17, making indigo = 11; theſe three added make the compounded indigo - - 50
Yellow = 14, being compounded of green = 17 and orange = 8, the three make the compounded yellow 39
Red, as in the ſpectrum = - - - - 11
This combination produces white = - - - 100

Beginning therefore with any of the ſeven colours in the ſpectrum, and taking the other colours in the order as above, fourteen combinations may be made, each producing white.

If four following colours be taken in the ſpectrum, as violet, indigo, blue, green, a ſhade intermediate to the ſecond and third will be produced, and white may be produced by that ſhade, or tint, combined with one priſmatic colour.

Violet 22, indigo 11, blue 17, green 17, added, make 67 indigo blue.
Yellow 14, orange 8, red 11, added, make - 33 orange.
So *two* colours may be ſaid to make white - 100

Indigo 11, blue 17, green 17, yellow 14, added, 59 blue green.
Orange 8, red 11, violet 22, added, - - 41 red.
So a blue, green, and red, make a white - 100

The ſame holds good with the reſt of the ſeven colours; and which produces perhaps the moſt harmonious combination of colours poſſible, for dreſs, for apartments, or any ſubject where colours are employed for embelliſhment.

The effects of theſe combinations account for the impreſſions left on the retina of the eye, by viewing different coloured pieces of ſilk laid on white paper: if a piece, about an inch diameter, be held about half a yard from the eye, and looked ſteadily at a minute, and the eye be then directed to another part of the paper, a ſpectrum will be ſeen the ſize of the ſilk, but of a different colour, viz.

Red ſilk produces a blue green ſpectrum.
Orange - an indigo blue.
Yellow - a violet indigo.
Green - a red violet.
Blue - - an orange red.
Indigo - a yellow orange.
Violet - a greeniſh yellow.

Now theſe ſpectra are preciſely of the colours which (combined with that colour which produces them) compoſe white.

The above experiments alſo account for the ſingular effect of ſhadows when light paſſes through differently coloured glaſs (ſee the experiments, page 144). If two ſhadows produced by two candles, one tranſmitting the light through a coloured glaſs, the light of the other falling immediately on the object that produces the ſhadow, the effect will be

If the glaſs be Violet, the ſhadows will be violet, and green yellow.
Indigo, - indigo, and yellow orange.
Blue - - blue, and orange red.
Green - green, and red violet.
Yellow - yellow, and violet indigo.
Orange - orange, and indigo blue.
Red - - red, and blue green.

Colours that are faded, by being kept in darkneſs, become renewed by returning to light.

Catoptrics.—This branch of Optics treats of light, as reflected from variouſly figured poliſhed mirrors or bodies. How light is thrown back from the ſurface of bodies muſt be firſt enquired into. The reaſons for its being reflected by a kind of chemical rejection, or want of affinity, have been pretty copiouſly given. But as ſuch an opinion as that of the great Newton ought to be precedent to that of an humble admirer of his philoſophy, without title or academical honours, he begs leave to give that the firſt place, in ſpeaking upon the ſubject of Catoptrics.

If the edge of a knife approach (very ſlowly) a ray of light, paſſing through a hole made with a pin, in a thin ſheet of lead, into a dark room, the ray will be ſeen to recede from the edge of the knife, in the direction *a d*, inſtead of its uſual ſtraight direction *a b*; ſee fig. 5, Plate XXXV. This ſingle experiment has been thought ſufficient to eſtabliſh the doctrine, that light was reflected before it touched the ſurface of the reflecting body; that it approached that critical place, where the ſphere of attraction ended, and where the ſphere of repulſion began, and from that place was thrown back. As it has been proved, in the firſt lecture, that the elaſticity of bodies was occaſioned by the repulſive power of fire or light incorporated with them; and as all bodies in nature are ſubject more or leſs to the two contending powers of attraction and repulſion, there muſt be a ſpace or point where thoſe two powers will balance each other. Suppoſe, for inſtance, the line *a b*, fig. 10, Plate XXXIV. was the ſurface of a body; and the line *c d*, the boundary of attraction and repulſion; that is, the place where the ſphere of attraction is ſaid to end, and where the ſphere of repulſion begins, as repreſented by the arrows in the figure. It is not, however, to be underſtood, that the ſphere of attraction completely ends at *c d*, or that repulſion begins there; but that the attractive tendency towards *e*, and the repulſive tendency towards *g* (from the fire within the body), balance one another at *c d*. But as heat increaſes the repulſive power of fire, either in a latent or an active ſtate, and cold diminiſhes it, the line *c d* muſt be very uncertain in its diſtance from, or in the body; for, in extreme cold, I ſhould ſuppoſe the boundary would be within the body. But, in hot or cold, colours remain much the ſame, and light is reflected much alike. How is this reflection then to be brought about, by an imaginary ſpace, where the ſphere of attraction is ſaid to end, and that of repulſion to begin? Reflection may be aſſiſted by an emanation from the reflecting body of the light it has already imbibed; and, when in a ſtate of heat, may emanate ſo powerfully as to turn the weaker rays back, before they touch the reflecting body. Chemical attraction is but the attraction of coheſion, applied to particular bodies, ſaid to have an affinity, or choice, in their union with one another. Diamonds have an affinity to light; ſo have various phoſphori: white bodies may alſo be ſaid to have a chemical averſion to light, and to throw it all off: other bodies may only have a chemical rejection to a particular part of light; as green cloth rejects the green, and abſorbs the other ſix parts of the light that fall upon it: other bodies may reflect two colours, ſo mixt, that they are diſtinct from any of the ſeven primitive colours. Therefore, from the ſhades and mixtures of different colours, ariſe that diverſity of hue in ſilks, cottons, linen, &c. that almoſt exceeds the power of numbers. It is true, dyes do but conſiſt of three colours, red, blue, and yellow; for from theſe (by mixture) can all the reſt be made.

When light impinges, or falls, upon a poliſhed and flat ſurface, rather more than half of it is reflected, or thrown back, in a direction ſimilar to its approach; that is to ſay, if it falls perpendicularly on the poliſhed ſurface, perpendicularly it is reflected. But if it falls obliquely on the looking-glaſs *a b*, fig. 2, Plate XXXV. *with the ſame obliquity it will be reflected.* The incident ray *c d* is thrown back in the direction *d o*, making with the perpendicular, *d s*, the ſame angle that *c d* does with it. For it is a rule in catoptrics, *that the angle of incidence is always equal to the angle of reflection*; that is, the angle *c d s* is equal to the angle *o d s*, in all caſes of obliquity. So a ray from the ſtar *d*, falling on the looking-glaſs *a b*, fig. 3, Plate XXXV. would be reflected to the eye at *e:* but as we ſee every thing along that line in which the rays come to us laſt, the ſtar *d* is ſeen at *s*; agreeably to the above law, that the angle of incidence *e o n*, is equal to the angle of reflection *n o d*.

Why do I ſee my face in a looking-glaſs?—If the face be ſtrongly illuminated by the ſun, or a candle, it may be ſaid to emit light, particularly towards the mirror *a b*, fig. 12, Plate XXXIV.: but (not to croud the figure with lines) we will take a ray from the forehead *c e*, which, agreeably to the angle of incidence, and reflection, will be ſent to the eye at *o*: but the mind puts *c e o* into one line, and the forehead is ſeen at *b*, as if the lines *c e o* had turned on a hinge at *e*.

Indeed it ſeems a wonderful faculty of the mind, to put the two oblique lines, *c e*, and *o e*, into one ſtraight line *o b*; yet is it ſeen every time we look at a mirror; for the ray has really travelled from *c* to *e*, and from *e* to *o*, and it is that journey that determines the diſtance of the object: and hence we ſee ourſelves as far beyond the looking-glaſs as we ſtand from it. Though a ray, in this caſe, is only taken from one part of the face, it may be eaſily conceived, that rays from every other part of the face muſt produce a ſimilar effect; and, therefore, that the whole face will be ſeen as far beyond the glaſs as the face is from it.

As the human eye is placed in the higheſt part of the body, the whole perſon may be ſeen in a looking-glaſs of but half its length and breadth; as in the mirror *a b*, fig. 6, Plate XXXV. the rays from the head travel to the mirror in the line A *a*, perpendicularly to the mirror, and are returned to the eye in the ſame line, viz. *a* A: conſequently, having travelled twice the length A *a*, a man muſt ſee his head at B; rays from his feet C, impinging on the bottom of the mirror at *b*, will be reflected to the eye, in the direction *b* A. But ſeeing his feet along the ray that approaches his eye laſt, he ſees his feet at *d*, along the line A *b d*, and ſo of all the reſt of his perſon.

Theſe examples may ſerve to prove that the angle of incidence, and the angle of reflection, are always equal: and, if properly underſtood, will eaſily explain the effects of diverging and converging rays; of concave, convex, cylindrical, or any other kind of mirror.

If rays come diverging to a mirror, they will diverge, in their reflection, the ſame as if they had gone forward: thus the rays *a b* and *b c* would go on towards *f* and *g*, if not met by a mirror; but by it they are turned into the direction *m n*, fig. 7, Plate XXXV.

The converging rays *a b* and *c d*, fig. 8, Plate XXXV. would go on, and meet at *o*, if not prevented by a plane mirror, which ſo turns them as to make them unite at *n*.

Converging rays, iſſuing from the object *a b*, fig. 9, Plate XXXV. would be narrow enough to enter the pupil of the eye at *c*; but being met by the mirror *d e*, they reflect converging to the eye *n*, which ſees the object *a b* at *s*, behind the glaſs, with the ſame obliquity as it was before the glaſs.

As a circle may be conceived to be made up of innumerable ſtraight lines, ſo may a globe, or a ſlice of a globe, be conceived of innumerable ſmall flat planes: theſe planes, lying obliquely to one another, will reflect the rays of light diverging; and, of courſe, convex mirrors ſpread out the rays that fall upon them; thereby diminiſhing the appearance of the object, and painting it nearer to the mirror.

Fig. 10, Plate XXXV. *a b*, is a dart, to be ſeen in the convex mirror *c d:* but though rays iſſue from the dart in all directions, and to every part of the mirror, yet it is only thoſe that fall upon it in the ſpace between *o* and *n* that can be reflected to the eye; agreeably to the law, that the angle of incidence is always equal to the angle of reflection. This law ſends the rays *o r* and *n r* more diverging than if the mirror had been out of the way; for in that caſe they would have united at *p*. Hence the angle *o r n*, being ſo much leſs than *a p b* (had the eye been at *p*), the image *s* will be leſs than the object, and nearer the mirror.

N.B. Large objects near a convex mirror, appear bent; becauſe one part of the object is nearer the mirror than another, ſo as to produce a ſenſible difference of angle: this is ſometimes called the aberation of ſphericity.

A perſon looking at his face in a convex mirror, has it diminiſhed, as fig. 11, Plate XXXV. To keep the figure diſtinct, a ray may be taken from his forehead, and another from his chin. Now, though rays flow from his forehead ſo as to cover the whole mirror, it is only the ray that falls at *c* that can (agreeably to the law reſpecting the angle of incidence and reflection) be reflected to his eye. But his eye, transferring every image along that line in which the ray comes to it laſt, ſees his forehead along the line *o c n*. So the ray from his chin *a r* will, agreeably to the ſame law, be reflected to his eye at *o*, and of courſe he will ſee his chin along the line *o r s*. Now the angle of viſion, *n o s*, being ſo diminiſhed, the reſt of his features will be ſeen diminiſhed in like proportion.

Concave mirrors enlarge the appearance of objects, by increaſing the viſual angle, for the ſame reaſon that the convex diminiſhes objects by contracting the angle. Both concave and convex mirrors are generally a portion of a ſphere; and the inner ſurface of a ſphere brings parallel rays to a focus at one fourth of its diameter, as may be ſeen in fig. 12, Plate XXXV., where ſolar light would unite and burn at the focus *a*. Or, if a candle were placed in that focus, its light would be reflected parallel, as in the figure.

The magnifying power of the concave mirror may be illuſtrated by fig. 1, Plate XXXVI. where a face, A, is looking at itſelf. We ſhall here again, for the reaſon given, only take a ray from the forehead, and another from the chin. Rays iſſue from every part of his face upon all parts of the mirror: but it is only *a c* that can paint his forehead; that ray is reflected to his eye from *c*; and as he ſees every thing along that line in which the ray comes laſt to his eye, the mind puts the lines *a c* and *o c* together, and they make the line *o c d*, the real diſtance which has been travelled by the ray from his forehead, and where his forehead will be ſeen. Certainly rays iſſue from his forehead on all parts of the mirror; but thoſe rays that fall on the mirror at *g*, would be reflected to his chin uſeleſsly, ſince he cannot ſee with his chin. In ſhort, it is only that critical place *c* which (by the law of the angle of incidence and reflection) can be reflected to his eye.

The ray from his chin, that falls upon the mirror at *n*, will, by the ſame law, be reflected to his eye; and along the line *o n q* he will ſee his chin. The whole viſage being, therefore, ſeen under the angle *d o q*, muſt be greatly magnified.

If the dart *a b*, fig. 2, Plate XXXVI. be held above the eye, and before a concave mirror, *c d*, it will be ſeen by an eye at *o*, magnified, at *s t*. For the ray *b n* will be reflected to the eye in the direction *n o*: ſo *b n* being put to the end of *n o*, *b* will be ſeen at *s*.

A ray, *a m*, from the other end of the dart, will approach the eye in the direction *m o*; and *a m* and *m o* put together, will make the line *o m t*, where that end of the dart will be ſeen, conſequently the dart *s t* will be the image of the object *a b* greatly magnified.

Theſe effects only take place when the object is between the mirror and its focus. But when the object is farther diſtant than the focus, the rays croſs, and the object (if ſeen) is ſeen before the mirror, and inverted. Thus, if the concave mirror be large, as *a b*, fig. 4, Plate XXXVI. and a hand be held up before it, and without its focus, its image inverted will be ſeen hanging in the air at *m*. For rays go diverging from a point, as *c* and *d*; and by the mirror are brought again to a point at *o* and *s*, where they croſs, and in that ſtate proceed to the eye.

Hence if a man, holding out a ſword, approach a large concave mirror, an opponent ſeems to meet him with a drawn ſword: and a perſon holding out his hand in approaching the mirror (at a diſtance farther than the focus), will have another meeting his, as if inclined to ſhake hands with him. If the hand turn a little on one ſide, the image will move the contrary way, &c. Hence alſo thoſe deceptions (where a mirror is concealed), of birds and angels flying: the hand attempts to lay hold of them, and finds them nothing. A noſegay is ſeen, and when the hand attempts to take hold of it, a death's head ſnaps at it, &c. &c. If a large concave mirror be ſo placed before a bright fire, that its image may be ſeen on a table; thoſe unacquainted with the cauſe, expreſs the utmoſt aſtoniſhment on ſeeing a fire burning on a table!

If two large concave mirrors be placed oppoſite each other, as fig. 5, Plate XXXVI. at any diſtance, and red-hot charcoal be held in the focus at *a*; a match, or brown paper, or any thing very combuſtible, held in the other focus at *b*, will be preſently ignited: ſhewing that common culinary fire is liable to the ſame flexibility as light.

Hold a decanter, half full of water, a little farther than the focus, from a concave mirror; and the decanter will be ſeen inverted: if then the water be poured into a baſin, the decanter will appear in its natural ſtate, and to be filling inſtead of being emptied.

Theſe deceptions may be multiplied into innumerable varieties. Prieſtcraft, availing itſelf of the properties of the concave mirror, rekindled the veſtal fire: and Archimedes is ſaid to have burnt the Roman fleet with one.

Anamorphoſes are produced from the pictures of objects as ſeen in concave cylindrical mirrors; which diſtort objects by bending their images into the ſame curvature as the mirror: thus, if a face look at itſelf in the cylindrical mirror *a b*, fig. 3, Plate XXXVI. it will ſee itſelf elongated like the figure A. But if this figure were drawn, and a convex cylindric mirror placed before it, it would be brought back to its true figure B.

Having thus gone through what may be called the principles of optics, it is now time to apply theſe principles to the explanation of optical inſtruments, viſion, and the rainbow.

The rainbow is certainly the moſt beautiful meteor in nature.

As it never makes its appearance but when a ſpectator is ſituated between the ſun and a ſhower of rain, it follows, that the ſun and drops of rain cauſe the phenomenon. If an hollow glaſs globe be filled with water, and ſuſpended ſo high in the ſun above the eye, that the ſpectator, with his back to the ſun, can ſee the globe red ; if it be lowered ſlowly, he will ſee it orange, then yellow, then green, then blue, then indigo, and then violet; ſo that the ſame drop, at different heights, ſhall addreſs to the eye the ſeven primitive colours in ſucceſſion. *Example.*—Let A, fig. 8, Plate XXXVI. be a drop of rain, and S *d* a ray from the ſun falling on the upper part of the drop at *d.* It will ſuffer a refraction, and inſtead of going forward to *c*, it will be bent to *n*; there it will be in part reflected to *q*; for ſome will paſs through the drop to *m:* by the obliquity with which it falls on the ſide of the drop at *q*, that part becomes a kind of priſm, and ſeparates the ray into its primitive colours. Hence we find, that after a ray has ſuffered two refractions and one reflection, as in the figure, the leaſt refrangible part of it (the red) will make an angle with the incident ſolar ray of 42° 2 , as S *f g*; and the violet, or greateſt refrangible ray, will make with the ſolar ray an angle of 40° 17′, as S *c g*. This holds good at whatever height the ſun may chance to be in a ſhower of rain : if high, the rainbow muſt be low ; if the ſun be low, the rainbow is high : and if a ſhower happen in a vale when a ſpectator is on a mountain, he often ſees the bow completed to a circle below him. So in the ſpray of the ſea, or a caſcade, a circular rainbow is often ſeen ; and it is but the interpoſition of the earth that prevents a circular ſpectrum being ſeen at all times, the eye being the vertex of a cone, whoſe baſe (the bow) is in part cut off by the earth. The drop, therefore, in falling the diſtance *b g*, will addreſs to the eye, *g*, the ſeven colours in ſucceſſion ; but that ſucceſſion is ſo quick, and ſo many other drops fall through the ſame circuit in the ſame time, that the mind loſes the idea of ſucceſſion, as it would in a whirling firebrand, and the bow ſeems permanent ſo long as the ſhower continues in the proper direction from the eye. Cones, therefore, paſſing from the eye through a ſhower, and making the above angles with ſolar light, will always produce a rainbow: and hence, if ſeveral people are ſtanding together, looking at the bow, they every one ſee a different bow; for they are each the vertex of a different cone. The bow, therefore, moves as the ſpectator moves; for the eye E, fig. 6, Plate XXXVI. by the ſmalleſt motion ceaſes to be the centre of the ſpectrum *a b*; and other drops, in another circle, producing the ſame effect, make him believe it the ſame rainbow. Suppoſe the outermoſt circle, *c c*, the plane, through which the drops falling, produce the red colour to the eye E; and that the loweſt circle, *d d*, produce the violet; ſo that the intermediate circles may be conceived as interior cones cut through the ſhower, one within another: then would drops paſſing through theſe ſurfaces produce the ſeven colours, though ſome might be within a few inches of the eye, and others ſome miles from it; for wherever the above angles took place, either in near, or in diſtant drops, the colour would ſtill be the ſame.

Theſe are the circumſtances that produce the interior or principal bow: but a faint exterior bow generally accompanies the principal bow. This is produced by drops of rain above the drop A, as B, where the ray to be ſent to the eye enters the drop near the bottom, and ſuffers two refractions and two reflections; by which the colours become reverſed, i. e. the violet is loweſt in the exterior bow, and the red is loweſt in the interior bow, and ſo of the reſt. The ray T ſuffers a refraction at *r*; part of it is reflected from *s* to *t*, and from *t* to *u*: we ſay part of it, becauſe a portion of the ray paſſes through the drop at *s* towards *w*, and another portion at *t* towards *x*: by theſe loſſes the exterior bow becomes faint and ill defined, in compariſon of the interior bow. Let us now carry theſe principles to the bow itſelf. The ſpectator A, fig. 1, Plate XXXVII. being in the centre of the two bows in the figure (the planes of which muſt be conceived as perpendicular to his view), the drops *a* and *b* produce part of the interior bow by two refractions and one reflection, as above; and the exterior, by the drops *c d* producing two refractions and two reflections: the ſun's rays being repreſented by the lines *s s s s*. The angle formed by the red ray in the exterior bow and the ſolar rays is of 51° ; and with that of the violet ray, of 54°.

On Viſion.—As the eye is the grand inlet to moſt of our pleaſure, no wonder that a more than ordinary attention has been paid to the ſtructure of that divine organ. It is placed in the higheſt part of the body to command diſtant proſpects ; moves eaſily in a cavity of bone in every direction ; is wiped and protected by lids that keep perpetually opening and ſhutting; and ſmaller accidents are prevented by a paliſado of laſhes. Its interior ſtructure is not leſs curious. Light only has natural acceſs to the ſenſitive part of this organ; but by any other impreſſion the optic nerve produces in the mind the idea of light: ſuch as a blow upon the eye ; thruſting the fingers againſt it; or a ſudden ſhock or ſurpriſe. This film is the medium between corporeal impreſſion and ſenſation; it is the handmaid that conveys to the mind images made upon it by light from outward objects. It is not ſight; but it is a ſcreen on which a picture is painted, and held to the mind's eye. This impreſſion is made by the optical inſtrument called the eye: the ſtructure of which is as follows:

1ſt. The ſclerotica, a ſtrong, unelaſtic coat, that holds tenaciouſly the optical part of the eye within it globular concavity; on the outſide of which are faſtened the muſcles that direct the eye towards objects, with their oppoſite ends faſtened to the cavity of bone in which the eye moves; ſo that, by the contraction and dilatation of theſe muſcles, the eye is moved in all directions with the utmoſt quickneſs. One part of the ſclerotica is tranſparent, and bulges a little out of the globular figure; as *a c*, fig. 3, Plate XXXVIII. In the human ſubject it is round, and forms the front part of the eye; in many other animals it is oval: this prominence is called the cornea; from its being ſo like horn, and ſo well calculated to tranſmit light.

2d. Within this lies a ſoft pulpy lining, called the choroid membrane, circle 2, fig. 3, Plate XXXVIII. black in the human ſubject, white in cats and owls, and green in animals that live upon graſs and vegetables: this ſeems a lining or bed for the optic nerve to lie upon; and is of too weak a texture to acquire motion by muſcular action, except at its extremities, which form a circular ring of muſcular fibres, called the iris, as *s s*, and theſe fibres ſurround a round hole for light to paſs through, called the pupil, as *o*. The iris, *s s*, is of different colours in different people, as blue, black, grey, &c. and ſuppoſed to be ſo irritable, as to be affected, and to contract, by ſtrong light, and relax by darkneſs, or weak light. This is very obſervable in a young child: when juſt awake, the pupil will be almoſt as large as the cornea, *a c*; but on being brought into the ſun, the pupil will contract to the ſize of a pin's head. A wiſe proviſion! for, as the child has not yet acquired ſtrength to move the head or eyes, was intenſe light to ſtrike the retina when the pupil was ſo open, it might injure that delicate membrane, ſo as to render it inſenſible, and induce the diſeaſe called *gutta ſerena.* By holding a candle cloſe to a cat's eye, the ſame contraction is obſervable.

3d. On the choroid membrane lies the retina, or optic nerve, the ſenſitive part of the eye, circle 3, fig. 3, Plate XXXVIII. This nerve, like all others, is but a continuation of the medullary matter of the brain; it enters the eye on one ſide of the axis, or line of viſion, at *u*; and, like a fine net, ſpreads over the whole interior ſurface of the eye. It is of an aſh-coloured white; ſo that by the black bed, or back ground, on which it lies, colours and ſhapes muſt be very diſtinct upon it;—for it is on this fine membrane that objects are painted by the cryſtalline humour, as a window would be by a common ſpectacle-glaſs, on a ſheet of paper;—from which picture our mind conceives the ſhape, the colour, and diſtance of all objects we look at. This film is repreſented in ſection by line 3, but its entrance, *u*, is inſenſible; for if three black ſpots, of about half an inch diameter, be placed in an horizontal line, a foot from each other, as *a b c*, fig. 7, Plate XXXVIII. and a perſon ſtand four feet from them, if he cover his left eye, A, and look ſteadily with the other at the left-hand ſpot, *a*, the middle ſpot, *b*, will diſappear, though he will ſee plainly the two outſide ſpots, *a* and *c*. But on looking with both eyes at the three ſpots, it will be evident, from the figure, that the ſpot *b*, which falls on the entrance of the optic nerve in the eye, B, will not fall on the optic nerve in the eye, A; and therefore, in looking at the three ſpots with both eyes, we ſee them perfectly. A blood-veſſel enters the eye with the optic nerve, and ſeems to indicate a muſcular energy in it; particularly at its extremities in the *ligamentum ciliare*, which unites it with the cryſtalline humour, *d*, at *b b*, fig. 3, Plate XXXVIII. This radiant proceſſus ſurrounds the cryſtalline humour, *d*; and perhaps, by its muſcular force, may elevate or depreſs it, ſo as to adapt the humour to near or diſtant objects. For the vitreous humour, B, which fills up the general body of the eye, is a jelly-like tranſparent ſubſtance, very flexile, and capable of ſuffering the cryſtalline humour to be depreſſed into, or elevated above it; ſo that the eye may be a globe, or a prolate ſpheroid (an egg-like figure), as is moſt convenient for ſeeing near or diſtant objects. This we conceive to be the uſe of the ciliary ligament; for certainly the eye aſſumes a different figure, whenever we ſtrain it to ſee diſtant, minute, or indiſtinct objects.

5th. The cryſtalline humour, *d*, is a lens of great magnifying power, very denſe, and made up of thin lamillæ, ſo that if ſome of the coats become diſeaſed, and opaque, as in the cataract, they may be ſeparated or depreſſed, without much injury to the reſt; though it is not uncommon to extract the whole lens, or preſs it into the vitreous humour. This lens has its focus on the retina, and, like other lenſes, paints any luminous or illumined object at that focus. The middle part of it may be ſeen through the pupil of the eye; its outſides are wiſely covered by the iris, to prevent priſmatic colours from confuſing viſion; for the edges of all deep magnifying lenſes are, in reality, priſms. It is made ſtill more achromatic by,

6th. The aqueous humour, *o s s*, which, with a limpid water (incapable of freezing), fills up the ſpace between the cornea, *a c*, and the cryſtalline, *d*; and in the middle of which is the iris, *s s*. Theſe are the coats and the humours of the eye, which is, as we have ſaid, an optical inſtrument, admirably calculated to paint objects on the retina or optic nerve: for inſtance, if I were looking at my pen, its picture on my retina would be the bent inverted figure, ſeen in the eye A, fig. 6, Plate XXXVIII. agreeably to the effect of the double convex lens, as before explained. But, if inverted, why do I ſee it upright?—All our ſenſes may be ſaid to be modifications of the ſenſe of feeling. When I lay a finger upon my arm, the nerves paſſing that place, convey to my mind the ſenſe of feeling. —If I preſs that finger againſt my eye, the retina conveys to my mind a ſenſe of light: impreſſions of a like nature made on my tongue, or the receſs of my noſe, would produce the ſenſations of taſte and ſmelling: and could I touch the nerves of the ear with my finger, no doubt, the ſenſation would be like a clap of thunder, or ſome prodigious noiſe. All which ſhews our ſenſations to be produced by mechanical impreſſions: and light, as a material and moving ſubſtance, can make a mechanical impulſe upon the ſenſitive part of the eye, and produce upon it ſomething like feeling; (for the boy couched by Cheſelden thought, when he firſt ſaw the light, that every object touched his eyes). But the retina differs from the nerves of feeling, in that it has no perception *where* the impreſſions of light are made upon it. It was neceſſary for our preſervation, that we ſhould promptly diſtinguiſh where any impreſſion was made on the outſide of the body; but, for a ſenſe incloſed within the ſkull, that kind of perception was unneceſſary; and we never find that nature does any thing in vain. Could I perceive, that when I hold a candle below my eye, it was painted on the upper part of the retina; or that when I held the candle above my eye, it was painted on the lower part of the retina; the objects I look at would certainly appear, as the picture, inverted. But I have no ſuch perception: I only know, by diſſection, in cutting away the ſclerotica and choroid membrane from the back part of the eye, and holding a candle before it, that the candle is inverted, and painted as above. But the dead eye has all the parts of the living eye, and therefore the effects muſt be the ſame. The end of the pen *c*, fig. 6, Plate XXXVIII. being painted at *a*, and the other end, *d*, at *e*, ſhews the pen inverted; but I do not feel it inverted; the retina does not inform me that the top is painted at bottom, and *vice verſa:* but as it is a property of the mind, to transfer every object along that line in which the rays approach the eye laſt, the rays from *c* approach the retina at *a*; and the rays from *d* touch the retina at *e*. The mind, therefore, transferring the end *c* along the line *a g c*, to the place where it is; and the end *d* along the line *e g d*, to the place where it is; of courſe the object muſt appear to the mind upright, notwithſtanding its inverſion on the retina. Diſtinct viſion requires the rays iſſuing from any object to come tolerably parallel; for, the more they come to the eye converging, the more indiſtinctly is the outſide of the object ſeen.

Objects appear large or little according to the angle in which the rays from them approach the eye: thus, the picture of my pen on the retina of the eye B, fig. 6, Plate XXXVIII. is but half the ſize it is in the eye A; becauſe it is twice the diſtance from it: for the angle of viſion, *c g d*, is double that of *c f d*. Yet I can judge of the ſize of the pen at B as juſtly as at A; but this is from experience; for we learn to ſee by time and obſervation. A child graſps at the moon, as it would at a candle within its reach; and a perſon couched, and brought to ſight of a ſudden, believes, as before obſerved, that every thing touches his eyes. Had the ſtudy of optics, or nature, been a part of the education of our forefathers, ghoſts and apparitions would not have affected their imaginations. Indiſtinct viſion in the night, mineral and animal matters mixed with light, ſpontaneous ignition by inflammable exhalations, and electricity, &c. would have accounted for the cauſe of all their fears. For the impreſſions made on the retina, like pain in feeling, will laſt many ſeconds after the impreſſion has been made; ſo that ignorance would conceive ſomething ſeen, even when the eyes were ſhut. If the eye meet a glowing ſun, and inſtantly cloſe, a white image of him will be ſtrong on the retina: continuing ſhut, the image will turn violet, then blue, then green; and, if the impreſſion were very ſtrong, may go in gradation through all the priſmatic colours. Is it not probable that the retina has a power of abſorbing light, and that the weakeſt is abſorbed firſt, the blue next, and the red (as the ſtrongeſt) laſt of all? Heat, however, expels latent fire, or light: Canton's phoſphorus, hermetically ſealed in a glaſs, and held in the ſun to imbibe light, is quite dark in a dark room; but if held near a hot iron, the light will appear ſo vivid, that the hour may be ſeen upon a watch in the dark: but the whole of this light may alſo be expelled by heat; and it will become quite dark till again impregnated with light by being expoſed to the ſun. Common phoſphorus, heated by being rubbed between pieces of brown paper, inſtantly ignites. Fuel will not part with its latent fire, until it is heated, &c. &c. and iron will not burn, even in vital air, till heated.

The general defects of the eye are, too long a ſight, or too ſhort; and ſquinting. As the cryſtalline humour partakes of the general decay of old age, and grows flatter; ſo its focal length increaſes;

hence age is obliged to hold objects very diſtant from the eye, to make their image come to a convergence on the retina; otherwiſe, if held at about ſix or eight inches (the uſual diſtance for diſtinct viſion), the image would be imperfect on the retina, as the focus of the cryſtalline is farther than the retina: this will appear in fig. 2, Plate XXXVII. in the eye A; where the flatneſs of the cryſtalline, *c*, would have its focus at *r*, beyond the retina, *e*. This defect is remedied by the ſpectacle-glaſs *d d:* which may be conſidered as a part of the cryſtalline; making up, by its bulgency, the want in the cryſtalline; ſo that both together they make one lens of the ſame focal length as the cryſtalline was in youth; and the image becomes diſtinctly painted on the retina. This ſpectacle muſt increaſe in bulgency as the cryſtalline grows flatter; and hence the neceſſity of its frequent change.

The ſhort-ſighted defect ariſes from the cryſtalline and cornea being too convex: for by bringing the rays to a focus in the vitreous humour at *r*, before it reaches the retina, as in the eye B, fig. 4, Plate XXXVII. the image will be as indiſtinct as in the old eye. Hence, without a ſpectacle, objects are held cloſe to the eye, that the rays may converge farther back: but a concave ſpectacle, *c c*, by its attraction towards its edges, ſpreads the rays outward, and thereby counteracts the too great contraction of the cryſtalline; ſending forward the image *r* to the retina *g*; agreeably to a former doctrine relative to the effects of concave lenſes.

Squinting is a diſeaſe of the muſcles which move the eye in its ſocket. If one becomes rigid, and will not give way to the action of the other muſcles, this will hold the eye in one poſition; as is the caſe with thoſe eyes that always ſeem looking towards the noſe.

Other eyes ſquint partially, as when the muſcle that directs the eye one way, is not a balance for its antagoniſt muſcle.

A ſpeck, or cataract, is ſometimes on the cryſtalline, and ſometimes on the cornea; commonly occaſioned by inflammations in the eyes. If it be before the pupil, its opacity, ſtopping the rays of light, occaſions blindneſs. The edge of the cornea being ſeparated from the white of the eye, needles can be introduced to depreſs the ſpeck, ſcratch it off, preſs the whole cryſtalline into the vitreous humour, or totally to extract it. Nature will ſupply another cryſtalline, or fill up the cornea with a matter that will ſupply its place, with the aſſiſtance of a deep or bulging ſpectacle.

Optical Inſtruments.—The Galilean teleſcope is one of the moſt ancient inſtruments of its kind; called ſo from the juſtly-celebrated philoſopher Galileo, of Tuſcany. This teleſcope, with which he diſcovered Jupiter's ſatellites, &c. conſiſts only of two glaſſes, a convex and a concave lens; and is, at large, what our opera-glaſſes are in miniature. Suppoſe *a b*, fig. 5, Plate XXXVII. a dart at a diſtance, which I want to magnify: if the object-lens *c d* (in the end of the tube) be held parallel to the dart, it will bring the rays from it to a focus at *r n* (according to former explanations), and a paper held there would exhibit the picture *r n*, if the object *a b* be ſufficiently illuminated. But if I interpoſe between the picture and the lens the concave *e f*, whoſe attractive power is towards its outſide; it will then turn the ray *b c o r* into the direction *b c o q*; and the ray *a d o n* into the direction *a d o m*; and ſo of the rays *a c n* and *b d r*. The lens, *e f*, is made in the figure much too large, that it might not be perplexed with crowded lines; but it muſt be ſuppoſed, when held cloſe to the eye, that the ſpace *o o* is not bigger than the pupil of the eye; ſo that the diverging rays *o q* and *o m* are continued to the retina. But this cannot be true, for only a few of the rays enter the eye, and therefore the object is ſeen very imperfectly; and the inſtrument is ſeldom uſed but for ſhort diſtances, as in opera-glaſſes, &c. Now as that ſenſe tranſfers every object along that line in which the rays laſt approach it, the lower end of the dart is ſeen along the line *q o s*; and the upper end along the line *m o t*; the image magnified and brought nearer. The diſtance between the two lenſes muſt be the difference between their focal lengths; i. e. if the focal length of the lens *c d* be twelve inches, and that of *e f* four inches, then the difference is eight inches, the length of the tube; and the magnifying power will be three times: (the number of times the focal length of *e f*, is contained in the focal length of *c d)*.

This teleſcope has the moſt light of any; but the ſmallneſs of the field of view is its greateſt defect.

The Night-Glaſs—Is a refracting teleſcope for diſcovering diſtant ſhips in the night: it commonly conſiſts but of two lenſes; an object-glaſs *a b*, and an eye-glaſs *c d*, fig. 1, Plate XXXVIII. This inſtrument ſometimes has a double eye-glaſs to prevent priſmatic colours; but this is a defect, for every lens reflects and loſes a quantity of light from its two ſurfaces, and in the night there is no light to loſe: the lenſes, therefore, are large, to concentrate as much light as poſſible; and every object is inverted. The topmaſt *e f* (being all we ſuppoſe that can be ſeen above the water) having its light refracted by the object-lens *a b*, and brought to a focus at *g*, has its image there inverted within the tube of the inſtrument: the eye-glaſs *c d* being placed in coincidence with the focus of the object-glaſs *a b*, ſend the rays into the eye E, in the direction *c o* and *d n*, forming on the retina the image *o n*. Every part of an image being transferred along that line in which the rays approach the retina laſt, the bottom of the object, *f*, is ſeen along the line *o m*; and the top along the line *n s*, greatly magnified. As this teleſcope inverts all objects, they ſeem to move the contrary way to the motion of the inſtrument; and its magnifying power is as the focal diſtance of the object-glaſs to the focal diſtance of the eye-glaſs; i. e. if the focal diſtance of the object-glaſs be twelve times as much as that of the eye-glaſs, then will the object ſeen be twelve times as long, and twelve times as broad, as when ſeen by the naked eye. This teleſcope was made formerly of thirty or forty feet long; nay, its object-glaſs was ſometimes fixed upon the top of an high tower, ſo as to be adjuſted by a wire communicating with the eye-glaſs at bottom: for lenſes of a very long focus unite the rays, and prevent the priſmatic colours that generally ſurround the field of view, and, of courſe, leſſen the diſtinctneſs of the object. For ſeeing terreſtrial objects upright, we uſe

The Refracting Teleſcope.—This inſtrument differs not much in principle from the laſt; but by having two convex lenſes, *c* and *d*, fig. 8, Plate XXXVII. placed on the oppoſite ſides of the ſphere of their convexity, the image is rendered upright: and two eye-glaſſes, *e* and *f*, magnify the image, *s t*, to the ſize S T. The object, therefore, to be magnified, A B, being by the object-lens *a* brought to a convergence, and its image painted within the tube at *b*, the rays paſſing through *c* and *d* give the ſecond image *s t*: this image is ſo magnified by the eye-glaſſes *e* and *f*, that it appears to the eye, *z*, under the angle T *z* S.

But to render this inſtrument achromatic (that is, its field of view *colourleſs*), we muſt firſt enquire what cauſes the circular priſmatic rings of colour in ordinary ſpy-glaſſes. Let parallel rays paſs near the edge of the lens *w x*, as *v* and *n*, fig. 6, Plate XXXIX. and they will be found *not* to aſſemble in a point: the moſt refrangible part (the violet) will aſſemble at *o*; and the leaſt refrangible part (the red) at *p*; and ſo of the intermediate colours. Hence the focus of the lens, *w x*, will be a circle, whoſe diameter, *a b*, is perhaps half an inch, or more; of courſe ſuch an object-glaſs as this (its edges having this priſmatic effect) muſt tinge the field of view with red, blue, green, &c. Now the ſuggeſtions of Newton, the endeavours of Euler, and the finiſhing of Dolland, have united theſe ſcattered rays into one mathematical point. Theſe were the means, viz. The diſperſive power of glaſs is very different. *Crown-glaſs* is compoſed of ſand, fluxed by means of the aſhes of ſea-weeds, barilla, or kelp; and has the leaſt diſperſive power of any glaſs: *plate-glaſs* is made of ſand, melted by means of fixed alkali; and has a greater refractive or diſperſive power: and *flint-glaſs* is compoſed of flint-ſand, melted by means of fixed alkali and minium, and has a greater refractive or diſperſive power than either of the other. If, then, the lens *w x*, fig. 6, Plate XXXIX. be of crown-glaſs, and the concave lens *c d*, of white flint-glaſs (the concave of the ſame radius as the convex), they will fit into one another, and become, as it were, one lens. They are placed at a diſtance from each other in the figure, for eaſier explanation. Now, as the diſperſive power of the concave lens is towards its outſide, while that of the convex lens is towards its centre, they will counteract the effects of each other, and the leaſt refrangible ray will be made to meet the moſt refrangible ray at *z* and *y*. Thus the violet ray *w o*, being bent the contrary way by the lens *c d*, will meet the red ray, and all the reſt, at *z*; and the leaſt refrangible ray, viz. the red, *w p*, being bent at *i*, will paſs on to *z*, croſſing the general focus there. The ſame effect will be produced on the rays *x o* and *x p* by the concave lens *c d*, and they will aſſemble at *y*. Now here are two colourleſs points produced, viz. *z* and *y*. Cannot they be united? Yes: by the convex lens *g h*; which will join the two focuſes in the mathematical point *k*. So that one combined lens is formed by two convex lenſes of crown-glaſs, and a concave lens of flint-glaſs between them.

This achromatic effect may be produced by an union of one convex and one concave lens; but not ſo well as by the above three: and the proportional denſities of the glaſſes to each other, require much profeſſional practice and attention; for the greater difference there is between the diſperſive powers of the convex and concave lenſes, a larger aperture can be admitted, and of courſe the object will be more enlightened. To produce this difference, lenſes have been made of two meniſcus glaſſes joined together, and filled with a pellucid liquor, the refractive power of which being much leſs than glaſs, would produce this difference; but it is difficult to keep any fluid from growing turbid for any length of time.

This compound achromatic object-glaſs giving ſo perfect an image of the object, can, in a tube of a few feet, admit of as great a magnifying power in the eye-glaſs as were in tubes of eighty or 100 feet long.

The moſt advantageous eye-glaſs is the one invented by Divini, and called Ramſden's eye-glaſs, being two plano-convex lenſes, with their *convex ſides inwards*, and placed ſo near as to be within each other's focus: the field of view is the moſt extenſive, and the image leaſt injured by the priſmatic effect of the edges of the lenſes.

In double convex lenſes, the moſt perfect is that whoſe radius of curvature of the firſt ſurface, is to that of the ſecond, as one to ſix: its aberration being the leaſt poſſible, viz. $\frac{15}{14}$ of its thickneſs: but if this glaſs is turned with its other ſide to the rays, the aberration will be $\frac{145}{42}$, and therefore would be much worſe. The ſame ratio holds good in concave lenſes.

N.B. The French plate-glaſs, and Engliſh crown-glaſs, reflect fewer rays, and admit more to paſs through, than any other kind of glaſs.

Common object-glaſſes will not bear an aperture and power larger than the following:

Focal Diſtance of Object-glaſs.	Aperture of Object-glaſs. Diameter.	Focal Diſtance of Eye-glaſs.	Magnifying Power.
Feet.	Inches.	Inches.	
1	0,545	0,605	20
2	0,76	0,84	27,6
3	0,94	0,04	33,5
4	1,08	1,18	39,5
5	1,21	1,33	44

The Reflecting Teleſcope.—This inſtrument performs by reflecting the rays iſſuing from any object, what the laſt did by refracting them. Let *a b*, fig. 8, Plate XXXVIII. be a diſtant object to be viewed: parallel rays iſſuing from it, as *a c* and *b d*, will be reflected by the metallic concave mirror *c d* to *s t*, and there brought to a focus, with the image a little further and inverted; agreeably to the effect of a concave mirror on light, as formerly deſcribed. The hole in the mirror *c d* does not diſtort or hurt the image *s t*, it only loſes a little light; nor do the rays ſtop at the image *s t*; they go on, and croſs, a little before they reach the ſmall concave mirror *e n*: from this mirror the rays are reflected nearly parallel through the hole *o*, in the large mirror; there they are met by the plano-convex lens *b i*, which brings them to a convergence at *m*, and paints the image in the ſmall tube of the teleſcope cloſe to the eye. Having by this lens, and the two mirrors, brought the image of the object ſo near, it only remains to magnify this image by the eye-glaſs *k r*; by which it will appear as large as *z y*, agreeably to former documents.

To produce this effect, it is neceſſary that the large mirror be ground ſo as to have its focus a little ſhort of the ſmall mirror, as at *q*; and that the ſmall mirror ſhould be of ſuch a concavity as to ſend the rays a little converging through the hole *o*; that the lens *b i* ſhould be of ſuch convexity as to bring thoſe converging rays to an image at *m*; and that the eye-glaſs *k r* ſhould be of ſuch a focal length, and ſo placed in the tube, that its focus may juſt enter the eye through the ſmall hole in the end of the tube.

To adapt the inſtrument to near or remote objects, or rather to rays that iſſue from objects converging, diverging, or parallel, a ſcrew, at the end of a long wire, turns on the outſide of the tube, to bring the ſmall mirror nearer to, or farther from, the large mirror; and ſo as to adjuſt their focuſes according to the nearneſs or remoteneſs of the objects. The ſun-glaſs, at the end of the ſmall tube, ſhould be unſcrewed when any other object, except the ſun, is looked at.

To eſtimate the magnifying power of the reflecting teleſcope, multiply the focal diſtance of the large mirror by the diſtance of the ſmall mirror from the image *m*; then multiply the focal diſtance of the ſmall mirror by the focal diſtance of the eye-glaſs *k r*; divide theſe two products by one another, and the quotient is the magnifying power.

Though reflecting teleſcopes are generally conſidered as better for celeſtial obſervation than refractors, they muſt be of an unwieldy ſize, or they want diſtinctneſs, becauſe it is calculated that not half the rays that fall on the ſpeculum are returned.

Of Microſcopes.—Theſe inſtruments aſſiſt the eyes in examining the minute parts of creation; and bring into view wonders of a different, though not of a leſs curious and extraordinary nature, than thoſe perceived by teleſcopes. They ſwell into magnitude atomical exiſtence, thereby ſhewing the animal economy to be as perfect in the mite as in the elephant; and almoſt oblige the mind to conceive an idea of organized nothing.

The Single Microſcope—Conſiſts but of one ſmall lens, as *a b*, fig. 4, Plate XXXVIII. Now the angle under which the eye would ſee the ſmall croſs (without the lens), would be the ſpace between the lines which go from the top and bottom of it to the eye. But if the lens be interpoſed between the eye and the object, thoſe lines would not meet at the eye; they would fall above and below it. But (by laws formerly explained) the rays *c a* and *d b* would enter the eye; and as the mind transfers every image along that line in which the rays approach it laſt, the top of the croſs will be ſeen at *m*, along the line *o a m*; and the bottom at *n*, along the line *o b n*. The angle of viſion being thus increaſed from *e o d* to *m o n*. The lens *a b* may, therefore, be conſidered as a ſpectacle-glaſs, and as having its magnifying power, from thus increaſing the angle of viſion.

It is alſo fitted up in a handle, with moveable tongs or forceps to hold plants, inſects, &c. and thence called a field, or botanic microſcope.

The Double, or Compound Microſcope.—This inſtrument, like the teleſcope, preſents the eye with the image, and not with the object itſelf, as in the ſingle microſcope, fig. 2, Plate XXXVIII. The lens *d e* is placed a little farther from the object *a c*, than its focal length; ſo that the pencils proceeding from each end of the object would unite at *o* and *n*, if not met by the lens *r s*. This image would be too large for the eye, or the eye-lens *t u*, to take in. For rays iſſuing from objects are very different from thoſe iſſuing from an image: an object may be ſeen on all ſides, if illumined by either direct or reflected light; but an image can only be ſeen in the direction of the axis of the lens that produces it; therefore the image *o n* is brought within the influence of the eye-glaſs *t u*, by the lens *r s*. If now the eye-glaſs *t u* be ſo placed, that the image *o n* be in its focus on one ſide, and the eye in its focus on the other, the top of the image will be ſeen along the line *z t m*, and the bottom along the line *z u v*, conſequently magnified under the angle *m z v*.

Solar Microſcope.—This entertaining inſtrument conſiſts of one plane mirror, and two lenſes: the mirror *s o*, fig. 5, Plate XXXVIII. is to be without the window ſhutter *d u*; the lens *a b* in the ſhutter; and the lens *n* within the dark room. Theſe three parts are united to, and in, a braſs tube; and the mirror can be ſo turned by adjuſting ſcrews, that however obliquely the incident rays A fall upon it, they (by the laws of the angle of incidence and reflection) can be reflected horizontally into the dark room through the illuminator *a b:* this lens collects thoſe rays into a focus near the object *c g*; where paſſing on through the object, they are met by the magnifier *n*; here the rays croſs, and diverge to the white ſcreen, where the image, or ſhadow, of the object, *q r*, will appear. The magnifying power of this inſtrument depends on the diſtance of the white ſcreen; and, in general, bears a proportion to the diſtance the object *c g* is from the magnifier *n*; that is, if the ſcreen be ten times that diſtance from the lens *n*, the image will be ten times as long, and ten times as broad, as the object. About ten or twelve feet is the beſt diſtance; for, if further, the image will be obſcure, and ill defined, though larger: the lens *n* is brought nearer to, or farther from, the object, by an adjuſting ſcrew, ſo as to exhibit the image clear and ſharp upon the ſcreen. This part of the inſtrument is calculated only to exhibit tranſparent objects, or rather ſuch as light can paſs through in part; but for opaque objects we uſe the

Opaque Microſcope.—Ores, flowers, inſects, ſhells, &c. are ſeen to great advantage by this inſtrument. The mirror *a*, fig. 6, Plate XXXVII. and the lens *c*, are the ſame as thoſe of the ſolar microſcope; but the converging rays from *c* are met by a diagonal mirror *e n*, which throws up the rays much condenſed upon the opaque object $s\ r$; from the object they are reflected to the magnifier o, from which they proceed diverging to the ſcreen $p\ q$, where the object will be painted, and greatly magnified.

The objects are generally ſtuck by a wafer, or glue, to a thin ſlider of wood, and not placed in the focus of the lens c, leſt they might be burnt.

The Magic Lantern.—The office of the ſun in the ſolar microſcope is performed in this inſtrument by a candle, or lamp; rays from which paſs through the lens a, fig. 7, Plate XXXVII., beſides others reflected by the concave mirror c. Theſe rays are interrupted by the inverted croſs, which, if coloured, muſt ſuffer them to paſs on to the magnifying lens e; here they ſuffer ſuch a refraction, as to go diverging to the ſcreen, where the croſs will be ſeen duly magnified. The lens e muſt be brought nearer to, or farther from, the object, till its focus exhibits the image clear and well defined on the ſcreen. Ludicrous figures, well painted in tranſparent colours, have a laughable effect in a dark room; and ſerious ſubjects, ſuch as the motions of the heavenly bodies, can be well repreſented by this inſtrument.

The Camera Obſcura—Is ſometimes made for viewing prints or pictures, and magnifying them; and ſometimes for taking landſcapes, &c. When the glaſſes are fixed in a box, or on a ſtand, their intent is to magnify pictures, as fig. 3, Plate XXXVII. where $a\ b$ is a plane mirror, placed at an angle of forty-five degrees with the horizon, and $c\ d$ a large lens, placed perpendicularly before it. If then a picture, $e\ f$, be laid inverted under the mirror $a\ b$, and be ſtrongly enlightened by the ſun, or by candles, rays iſſuing from it in all directions, thoſe that impinge on the mirror will be reflected to the lens *c d*; which will bring them to a focus on the retina of the eye E. Now the eye transferring every part of an object along that line in which the rays from it came to the eye laſt, the top of the object will be ſeen in its right poſition along the line E *c a i*, and the bottom along the line E *d k*, greatly magnified.

MISCELLANEOUS

EXPERIMENTS, DECEPTIONS, &c.

A FEW years ago the Brethren of the Trinity-houſe applied to me to give a deſign for a light on St. Mary's Iſle, in the iſlands of Scilly. That important ſtation required a light of great intenſity; of large volume; to be ſeen on all ſides; and to be diſtinguiſhed from all other lights. Conſidering that much light is reflected from the two ſurfaces of lenſes, and, of courſe, loſt to diſtant obſervation; and that mirrors added much to the natural light of a lamp, in one direction; I united ſeven parabolic concave mirrors in one perpendicular frame, as fig. 1, Plate XXXIX., with an Argand's lamp in the focus of each mirror. The mirrors were twenty-two inches in diameter, of copper, plated with poliſhed ſilver ſurfaces; ſo that the volume of light is five feet and a half in diameter, and appears like one united blaze of light at a diſtance: the reſervoirs of oil are fixed behind each mirror. To diſtinguiſh this light at ſea from all others, and to enlighten all ſides of the horizon in ſucceſſion, I contrived a machine to turn the whole frame of lamps round on the upright ſhaft, *a*, in two minutes; the light thus appearing and diſappearing at the end of every ſecond minute, gives the approaching ſeaman a perfect aſſurance *what* light it is. As it is a property of the parabolic curve to reflect the light that falls upon it, from *c* its focus, in parallel lines, as *d d*, &c. the whole ſeven mirrors ſend out a cylinder of light, that, as it paſſes the ſpectator, appears for a moment of unuſual ſplendor; ſo that by obſerving that, and the next return of its brilliancy, by his watch, he eaſily perceives it to be the Scilly light.

This was the firſt on this plan of ſeveral that have been copied from it.

2d. Large lenſes, and concave mirrors, painting the image of objects in their focus, if they are well enlightened, give ſcope for variety of deception: to ſtand, with the eye in the axis of a large convex lens, the image of the object will be ſeen in that line, as if ſuſpended between the lens and the eye. A large metallic, or glaſs, concave mirror, placed on the back part of a dark box, produces appearances that are truly ſurpriſing. Let *a*, fig. 3, Plate XXXIX. be the mirror; *d* the actor, concealed by the croſs partition *c*; *e* a ſtrong light, alſo concealed by the partition *i*. If *d* holds a book, or any other object, the light reflected from it will paſs between the ſcreens, or partition, *c* and *i*, to the mirror, and be from thence reflected to *z*, where the image of the book will appear ſo tangible, that the ſpectator, looking through the opening *x*, will ſuppoſe he could take hold of it. The confederate *d* may actuate various moving figures, as flying birds, angels, demons, &c. the effects of which at *z* would be very ſurpriſing.

3d. If the head of a pin (or any ſmall object), *a*, fig. 2, Plate XXXIX. be held near the eye, and before a ſmall hole in the black paſteboard *c* (the light, or the white paper *d*, being a background), the pin will appear on the oppoſite ſide of the board *c*, inverted, and magnified as *x*. The object *a* being within the focus of the cryſtalline humour *s*, will cauſe the image of it to be painted on the retina at *r* without inverſion; i. e. it will be painted on the optic nerve with the ſame end up as it is held in the hand, and, of courſe, appear inverted. But, in reality, it is the ſhadow of the pin that is painted on the retina; for the light from the lower part of the paper *d* will be ſtopped by the head of the pin; and that from the upper part will be ſtopt by the leg of the pin, in paſſing through ſo ſmall a hole as *a*; and thoſe rays cannot croſs within the eye as uſual, but will go parallel and upright to the retina; ſo that, to the mind, the object muſt appear inverted. A pin's head cannot be ſeen when held ſo near to the eye as to be within the focus of the cryſtalline humour, as at *a*, fig. 8, Plate XXXIX.; therefore the mind transferring it to that focus, ſeems to remove it behind the ſcreen *c*. For by the muſcles of the eyes they can be turned ſo that their axes may meet at any convenient diſtance with the moſt rapid facility, as at *b c d g*, &c. But when the mind is careleſs, or thinking on ſubjects in which the eyes have no concern, the muſcles return to the eaſieſt poſition, and often make each eye look a different way; ſo that the object *g* would be ſeen double, as *g g*.

4th. Radiant rays iſſuing from a cloud, ſeem as if the ſun was in the cloud; but this is one of thoſe celeſtial deceptions to which the eye is very liable. When the ſun is behind a cloud of various forms and thickneſs, rays iſſue from it, as fig. 5, Plate XXXIX.: theſe rays are reflected from the different parts of the cloud in various angles, yet all appear to the eye as if perpendicular to it, though ſome of them approach it almoſt in a direct line; for the eye being leſs accuſtomed to contemplate celeſtial then terreſtrial objects, it judges very erroneouſly of both diſtances and directions. Suppoſe the ray *a b*, fig. 4, Plate XXXIX. iſſuing from the luminous point *a*, and coming obliquely towards the eye *c*, the eye would foreſhorten it into the line *a d*: hence the radiant appearance of rays in the moiſture that ſurrounds the cloud.

5th. Thus are the ſhort rays, reflected from the moiſt and poliſhed edges of the eye-lids, lengthened, when they are nearly cloſed, and the eye directed to a ſingle candle, about ſix feet diſtant. Let *a c*, fig. 7, Plate XXXIX. be the eye-lids half ſhut; then will the rays *a b* fall obliquely on the ſurface *a*, and be from thence reflected through the cryſtalline humour to the retina at *d:* the rays *b c*, in like manner, will ſpread on the retina at *e*. But ſeeing every thing along thoſe lines that approach the retina laſt, the rays *d a* produce the unſteady ſpectrum *g b*; and the rays *e c* the ſame, in the direction *b b;* growing longer or ſhorter, as the eye opens or ſhuts.

6th. From the colour of ſhadows on a white ground; the colour of mountains ſeen at a diſtance; and what is called blue ſky; it appears, that the colour of the atmoſphere is a diluted blue; a colour that can only be perceived, when large maſſes of the air are looked through: hence the earth ſeems ſurrounded with a ſky of a blue colour; and painters give their diſtant mountains that hue. A very ſurpriſing effect of ſhadow is produced by placing a red flat piece of glaſs, *a*, fig. 9, Plate XXXIX. before the candle *d*, and holding a pencil, *c*, between it and the ſheet of white paper *x x*. If another candle, *g*, be placed a few inches from the firſt, two ſhadows of the pencil will be produced on the paper, *x x*; that from *d*, through the red glaſs *a*, viz. *e e*, will be a fine green; and that from the candle *g*, viz. *n x*, will be a deep red. Now, that the ſhadow *n x* ſhould be red, is not marvellous, becauſe it falls on a red ground, produced by the red glaſs, *a*; but why the interception of red light ſhould produce a green colour, on a white or any other ground, is a phenomenon in Optics not eaſily to be accounted for. (See page 106.) A mixture of blue and yellow makes a green; and the intermediate colour is always formed by the mixture of thoſe that go before and after it, in the priſmatic order, ſo as to reduce the ſeven to three primitive colours. If ſtrong white light be looked at through blue glaſs it will appear green; as in holding up the glaſs before a dull ſky, &c. Black and white, mixt on a pallet, produce a dirty blue; and the blue ſky has been ſuppoſed to be ſo produced, by the eye mixing the white of the atmoſphere with the blank ſuppoſed to exiſt above it. Now, as ſhadows on a white wall are of a dubious blue; may not that colour be the reſult of white light paſſing through a blue medium? and the near approach of blue and green to one another, make one, ſometimes, to be miſtaken for the other?

7th. If a ſhilling be put in a tumbler half filled with water, and then inverted upon a white plate (the plate being firſt inverted on the tumbler), a double deception will take place; the ſhilling will appear on the ſurface of the water as a ſhilling, but at the bottom like an half-crown piece:—making one ſhilling into three ſhillings and ſixpence! How is this?—By the refractive power of the water, the eye in a proper poſition will ſee the ſhilling on the ſurface of the water. But the tumbler itſelf (and the water in it) becomes a lens from its round figure, and magnifies the ſhilling into an half-crown piece.

LECTURE X.

ASTRONOMY.

SECTION I.

HAVING conſidered the materials of which our globe is formed, it is in the next place requiſite that we ſhould conſider it as a part of a ſyſtem; the ſtudy and knowledge of that ſyſtem, with the ſtarry heaven that ſurrounds it, conſtitute the noble ſcience of Aſtronomy:—a ſcience that has engaged the ſtudy and admiration of the firſt characters in all ages of the world; and is probably the earlieſt that was cultivated by mankind. For in the firſt ages of the world, when the buſineſs of the human race was to tend their flocks and herds, by night as well as by day, it is natural to ſuppoſe, when they had no other object to look at, they would turn their eyes towards heaven: and we accordingly find, in the remoteſt ages, that a planet was known from a fixed ſtar. But in thoſe times the uninformed mind ſaw divine vengeance in an eclipſe; and deſtruction in the tail of a comet: and prieſts and empirics, availing themſelves of ſo natural a ſuperſtition, contrived the fallacious and wicked impoſitions of aſtrology; by which the credulous vulgar have been the dupes of impoſtors, who pretended to foretel future events by the poſitions of the planets. Had a knowledge of the regular and orderly motions of the heavenly bodies done nothing more for mankind than expoſe and confute theſe deluſions, and wean the enquiring mind from ſuperſtitious fears and uncertainties, humanity ought to have bowed to a teleſcope, and made the pillar of a quadrant an altar whereon to ſacrifice its terrors and ignorance! But theſe illuſions are happily done away by this enlightening ſcience; and we can now look on comets and eclipſes with tranquillity.

In meaſuring time (ſo neceſſary in all human affairs), we have no invariable ſtandard but in the heavens. In chronology, the dates of ſome of the remoteſt events of antiquity are well aſcertained by the eclipſes that happened about the time. But the moſt important uſe of this ſcience is, that of teaching the adventurous navigator how to find his way over a trackleſs ocean. So that we may ſay, that the riches and comforts derived from trade and commerce are in a great degree owing to this ſcience. By it alſo is aſcertained the true figure of the earth; and the ſituation, ſhape, and extent of its continents and ſeas. But of all the means by which mankind have been led to a knowledge of the Deity, this ſcience undoubtedly affords the moſt conſpicuous! A view of the creation through the eye of aſtronomy, at once aſtoniſhes and overwhelms the mind! The grandeur of ſuch a ſpectacle, accompanied by an idea of that omnipotent Power, which made and governs the whole, exalts while it chaſtens our faculties; inſpires humility, while the underſtanding is ſtrengthened and enlarged; and finally leads us to a rational conception of the attributes and perfections of this great and good Being.

Before we launch out into that ſpace which ſurrounds us on all ſides, it may be neceſſary to take a ſurvey of this planet on which we live. Antiquity believed it to be a flat plane; and almoſt in our own time, the church conſigned a Sage to priſon, for teaching that it was a globe. But the many voyages that have been made round it, have proved its globular figure beyond all doubt. This may be eaſily perceived without performing ſuch a voyage; for when we firſt ſee a ſhip at ſea, her topmaſt alone appears, as if ſticking out of the water; as ſhe approaches nearer, we ſee her upper ſails; after a nearer approach, we ſee her lower ſails; and ſoon after, the hull itſelf. We ſhould certainly have ſeen the whole at once, had ſhe been approaching us on a plane; but it is evident that a bulging portion of the ſea intervened, which hid her from our ſight, until ſhe came ſo near us as to be on a comparative flat. The young aſtronomer will have his conception aſſiſted by inſpecting fig. 1, Plate XL. where the curve line *a b* repreſents a portion of our globe's ſurface. The ſhip *a* would be altogether hid from the ſpectator *c*, except its topmaſt, which would be ſeen along the line *d n*; when the ſhip arrives at *g*, her lower ſails would appear to the ſpectator *c*, above the line *d s*; and when ſhe comes to *m*, ſhe would be entirely ſeen.

In like manner, when we ſail from great capes, or headlands, we loſe ſight of thoſe eminences, firſt at the bottom; then the middle diſappears; and ſoon after the top: in approaching the land, the tops of the mountains firſt appear; then the middle of them; and when very near, the flat ſhore itſelf. Theſe appearances are univerſal; and prove that we always ſail upon a globular ſurface.

An eclipſe of the moon is occaſioned by her paſſage through the earth's ſhadow; now this ſhadow appears always circular on the moon's face, whatever ſide of the earth is turned towards her: ſhewing, that it is not a flat round body that projects the ſhadow, but a globe.

If we may be permitted to judge of this matter analogically (from that ſameneſs that runs through all nature), we can prove the ſun, moon, planets, and fixed ſtars, all to be globes. Can we ſee any reaſon, why the Almighty ſhould invert the general order and economy of the univerſe, for this ſpeck of earth on which we live, and which bears but an inſignificant proportion to many of the bodies in our own ſyſtem?

A pendulum vibrating ſlower at the equator than in France, firſt gave the hint, that the earth was not a perfect globe. But as heat expands metals, this might be ſuppoſed to occaſion the difference. A rod of iron, thirty feet long, will not expand above one tenth of an inch in the hotteſt ſummer's day; but a pendulum rod of 39.2 inches, which vibrates ſeconds at London, muſt be ſhortened one inch to vibrate ſeconds at the equator; therefore, gravity muſt be leſs, or the centrifugal tendency more: the latter is the cauſe; and it has been calculated that a body weighing 289lb. at the pole, would weigh only 288lb. at the equator. For the equatorial parts of the globe deſcribe ſo large a circle round the earth's axis every twenty-four hours, in compariſon of the parts nearer the poles, that the tendency to fly off not only diminiſhes the weight of bodies there, but has made thoſe parts ſwell into a protuberance, that diſtorts the ſimple and beautiful figure of a globe, into that of an oblate ſpheroid, or that of an orange or turnip. It was calculated by Newton, that this ſwelling would increaſe till the equatorial diameter ſhould be to the polar as 230 to 229, when it would ſtop, and become a balance to the power of gravity. It ſhould ſeem as if this muſt have taken place when the materials of the earth were in a ſoft or pulpy ſtate, and mixed together, ere land and water were defined or ſeparated. The fact, however, has been proved by actual menſuration, that the earth is about thirty-five miles in diameter from one ſide of its equator to the other, more than it is from pole to pole. Here we have a wonderful ſpecimen of human genius and invention! A pigmy of ſix feet, undertakes to aſcertain the true figure of a body 8244 miles in diameter! The places ſelected for this ſingular meaſurement, were under the equator in South America, and under the polar circle in Lapland. To give a general idea of it, we will ſuppoſe I want to know the diſtance of *a* and *b*, fig. 3, Plate XL.; either upon a plot of ice, or on level ground. I meaſure exactly a line that I make the baſe of a triangle; ſuppoſe that baſe to be *c d*. Stations muſt now be fixed upon in the neighbourhood, within ſight of one another, ſuch as churches, tall trees, flags on the tops of the hills, as *a*, *e*, *b*, &c. With a quadrant or theodolite at *d*, the angle *a d c* is taken*; and at *c*, the angle *a c d* is taken. The angles, and one ſide of a triangle, being known, the length of the other two ſides will be found by a ſimple proceſs in plane trigonometry: having thus found the length of the line *a c*, I make it a baſe of the new triangle *a c e*. Taking the angle *e a c* at *a*, and the angle *a c e* at *c*, I become poſſeſſed of the length of the line *a e*: this line I alſo make the baſe of a new triangle, viz. *a e b*. By taking the angle at *a*, and that at *e*, as before, I acquire the length of *a b*, the line ſought. This may ſerve to give a general idea, how inacceſſible diſtances may be found, and how the mathematicians proceeded at Quito, and

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* When three letters repreſent the three angles of a triangle, the middle letter is the angle in queſtion.

in Lapland. But when a line is thus meaſured on the meridian, or immediately north and ſouth, how is this to aſcertain the true figure of the earth?—Suppoſe the diſtance above found, to be an arch of the meridian *a b*, fig. 2, Plate XL. at the equator; and the arch *c d*, the ſame diſtance, and bearing, at the polar circle. Now a plummet, if ſuſpended at *a*, would point to the centre of the earth *e*, and alſo to the fixed ſtar *g*. The ſame performed at *b*, would alſo point to *e*, and to the ſtar *m*. Though we know nothing of the diſtance of the fixed ſtars, we can eaſily draw an imaginary circle through *g* and *m*, and know the number of degrees they are from each other. For all circles, great or ſmall, real or imaginary, are ſuppoſed to be divided into 360 parts, called degrees. So we find, with a common quadrant, how many of thoſe parts or degrees are contained between the ſtars *g* and *m*. This part of the ſurvey being finiſhed, we proceed with the line and plummet at *c* and *d* in the ſame manner, and find the line pointing to the ſtars *i* and *k*. Now, though the terreſtrial diſtance *a b* is the ſame as *c d*, the celeſtial diſtances *g m* and *i k* are very different, as may be obſerved even by the eye. Does not this, at firſt ſight, prove the earth to be flattened at its poles, and protuberant at its equator? or, in other words, that the arch *a b* is a portion of a ſmaller circle than *c d*, and of courſe that it will occupy a larger arch in the heavens? Theſe ſurveys being thus compared, it became eaſy to eſtimate how much the equatorial diameter exceeded the polar: which was about 35 miles; the length firſt calculated by Sir Iſaac Newton.

This effect is well repreſented by two circular rings, flexible, and croſſing each other, as fig. 4, Plate XL.; theſe turning ſlowly by the handle *a*, will appear like a globe; but if turned ſwiftly, they aſſume the ſwelling oblate figure of the earth.

But the young mind will naturally aſk this queſtion: If the earth be a globe, or any other figure like a globe, how can people ſtand on all ſides of it, and believe themſelves upon its top? When we firſt begin to reflect upon the ſubject, we are apt to carry our ideas downward, not only through the earth, but through all ſpace: in reſpect to ſpace, however, there is neither top nor bottom in it; on the earth, the whole of its ſurface is its top, and its centre is its general bottom. Not that we conceive there is an attracting ſomething there, which draws the materials of the earth toward it, and unites the whole in a denſe ball. In a former lecture, we have proved that the whole earth is the attracting body, and not any thing placed in its centre. If fig. 7, Plate XL. repreſent the earth, with inhabitants ſtanding radiantly round it, the figure *a* will be the moſt powerfully attracted towards his antipode *c*; becauſe there is the greateſt maſs of the earth under his feet in that direction; and the figure *c* will be the moſt powerfully attracted towards his antipode *a*, and he would therefore call that direction his downward. The figure *d* is attracted moſt towards *m*; and the figure *m* moſt towards *d*; ſo that if a hole were made through the earth, and they were to fall down it at the ſame inſtant, they would meet at the centre *o*, where they would be ſuſpended between contending attractions, and loſe all further ideas of downward, being at the general bottom of every place reſpecting the earth. If they purſued their journey towards their reſpective antipodes, the reſt muſt be performed up-hill, or rather as if they were climbing up the ſhaft of a mine. At firſt, indeed, that difficulty would be inconſiderable; but it would increaſe as they left a greater portion of the globe behind them, until they arrived at the ſurface, where it would be greateſt of all: for gravity diminiſhes from the ſurface of the earth, whether we go upwards or downwards. Is it not evident, therefore, that the whole ſurface of the earth muſt be its general top, and the bottom, to all parts of it, the centre? So vague are our ideas of upward and downward, that if the planet Jupiter were to approach our world ſo near that his attraction (from his ſuperior ſize) was greater than that of the earth; in his approach, we ſhould ſee him over our heads, and begin to feel ourſelves lighter; as he came nearer, we ſhould begin to riſe from the earth; preſently we ſhould fall to that body we juſt before had ſeen above us; and then the earth itſelf would be over our heads!

It is equally incomprehenſible to the uninformed mind, how it is poſſible that the earth ſhould turn round its axis every twenty-four hours, and we not perceive it. This, like many other celeſtial appearances, is fallacious. We ſee the ſun riſe in the eaſt, and ſet in the weſt. We truſt the evidence of our eyes implicitly in near objects, and with difficulty diſtruſt them in thoſe that are remote. But if the earth turns on it axis from weſt to eaſt, the ſun, moon, and ſtars, muſt certainly appear to turn the contrary way, or from eaſt to weſt: therefore thoſe bodies muſt turn round us, or we muſt turn round the earth's axis. Let us then enquire which of theſe is moſt conſiſtent with that wiſdom and ſimplicity we ſee in the other parts of creation. Mathematicians can certainly prove the ſun to be above a million of times larger than the earth; and nearly a hundred millions of miles diſtant from it. Aſtoniſhing! Can common ſenſe believe it poſſible that this huge globe ſhould revolve round the earth, to give it day and night, with a rapidity exceeding all imagination, when the earth by ſimply turning round on its axis, would have all the benefit of ſuch a revolution!—a common mechanic would be aſhamed of ſuch a machine. Nay, not only the ſun, but the whole heavenly hoſt, muſt make this rapid and unneceſſary revolution, was it as it appears to our eyes. We can ſee the other worlds of our ſyſtem turn on their axes; and, from analogy, might conceive that muſt be the caſe with our earth. It is true we feel no jolts or obſtacles, by which we generally judge of motion; for the earth flies through ſpace like a balloon through the air; where the aëronaut, inſenſible to motion, transfers it to the towns over which he flies. If we were in the cabin of a ſhip, when ſhe turns with the tide, on ſmooth water, and looking at fixed objects at a diſtance, our eyes would tell us thoſe objects were turning round us, and that we were at reſt. So are we deceived in the motion of the earth: for turning on its axis from weſt to eaſt, the heavenly bodies muſt appear as turning from the eaſt towards the weſt. We have proved that the air is held faſt to the earth by the power of gravity; and it muſt therefore revolve with it; ſo that if the medium in which we live be carried along with us, it will be impoſſible for us to perceive the earth's motion, except by means of diſtant objects: and hence a bird is as effectually carried forward when on the wing as when at reſt. So it is, that the eye deceives us in every celeſtial motion.

Beſides this diurnal motion, the earth has another, called its annual motion, which is a journey it performs round the ſun in 365 days 5 hours 48 minutes and 45 ſeconds. In this journey the ſeaſons are produced by a contrivance, as the poet juſtly eſteems it,

"Sublimely ſimple."

This was by inclining the earth's axis 23½ degrees from a perpendicular to the plane of its road, or the ecliptic, as is called; and by that axis continuing parallel to itſelf during this annual journey. By this beautiful contrivance, the northern and ſouthern hemiſpheres are brought alternately under the ſun, and his bleſſings in a great meaſure equally diſtributed over the face of the whole earth. This parallelifm will be eaſily underſtood by inſpecting fig. 8, Plate XL. where the line *n s* is the poſition of the earth's axis for every month in the year. The earth being divided into two hemiſpheres by its equator, *a b*, the northern one is addreſſed to the ſun in the month of June, and, of courſe, that half is in ſummer. In December, juſt the contrary takes place: the ſouthern hemiſphere becomes addreſſed to the ſun, and is in ſummer; while the northern is turned from the ſun, and conſequently is in winter. At the equinoxes, in March and September, the ſun is over the equator, and ſhines to the north pole *n*, and to the ſouth pole *s*: as theſe centres, therefore, are in the boundary between day and night, every circle on the globe will be cut equally by this boundary; and every ſpot on the earth will deſcribe one half of its diurnal revolution in the day, and the other half in night, and hence their equality at thoſe times of the year. In April the ſun will ſhine a little over the north pole, as may be ſeen in the fig. 8, Plate XL.; the day-part of the circle will be thus increaſed, and the night-part of it diminiſhed. In May, he ſhines more over the north pole, and the days increaſe in length; but in June he ſhines 23½ degrees over the north pole, ſo that all places within that diſtance of the pole have perpetual day; and the day-part of every place in the northern hemiſphere, beſides, has its longeſt days, as may be ſeen by a mere inſpection of the figure. In July, he does not ſhine ſo far over the pole; in Auguſt, leſs; and in September, he again ſhines no farther than to both poles, and equality of day and night again takes place. The earth's axis ſtill keeping nearly parallel to the line in which it ſet out, the north pole now ſinks into the dark half of the earth, and will not be in ſight of the ſun again for half a year, i. e. till the ſpring equinox: but ſo much as the ſun in October ſhines ſhort of the north pole, ſo much it will ſhine over the ſouth pole; in November, more; and in December, moſt of all, or 23½ degrees: therefore it is now midſummer in the ſouthern half of the globe, and midwinter to the northern half; as may be ſeen by an inſpection of the figure. A ſpectator on the earth in March, ſees the ſun in a conſtellation of ſtars called Aries ♈; in April, in Taurus ♉; May, Gemini ♊; June, Cancer ♋, &c.: ſo that the ſun is uſually ſaid to paſs through the twelve ſigns of the zodiac every year. The manner in which the ſun enlightens the earth, the parallelism of its axis, and the increaſe of days and nights, may be naturally repreſented by a ſmall terreſtrial globe, hung by a ſtring faſtened to its north pole, fig. 1, Plate XLI. A circle of wire, *a b*, repreſenting the plane of the earth's equator, may be held parallel to the table, and even with a candle ſtanding upon it. If the ſtring be twiſted a little towards the left hand, and the globe ſuſpended even with the wire at *a*, the globe will begin to turn on its axis from weſt towards the eaſt, and day and night will be ſtrongly depicted on its ſurface by the candle. But if the globe be carried round the wire, to repreſent a year, the candle will illumine it to both poles, and every ſpot on its ſurface will deſcribe half a circle in the enlightened part, and half in the dark part, and make equality of day and night through the air. This is, however, not the caſe in nature; for the plane of the equator inclines 23½ degrees from the ecliptic, or plane of the earth's road round the ſun: if then the wire be held with that inclination, as *a b c d*, and the globe be carried gently round it, the ſeaſons, and increaſe of day and night, will appear as they are in nature; i. e. when the globe is at *a*, the candle enlightens it no farther northward then the arctic circle *n o*; all within which, in the middle of our winter, is deprived of a ſight of the ſun; while all places within the antarctic, or oppoſite circle, have perpetual day: at this time the candle ſhines vertically on the tropic of Capricorn. As the earth moves towards *b* (the vernal equinox), if a ſmall patch be laid on latitude 50° north, it will ſhew how the days increaſe in England, and how the nights decreaſe. When it has arrived at *b*, the candle will then be perpendicularly over the equator; and, ſhining to both poles, equality of day and night will take place: as it proceeds towards *c* (the ſummer ſolſtice), the days increaſe, and the candle ſhines more and more over the north pole: when it has arrived at *c*, the whole arctic circle, and the countries it includes, will revolve in continual ſight of the ſun; and all within the antarctic circle will be deprived of that ſight. At this time the candle ſhines vertically on the tropic of Cancer. Moving from midſummer towards *d* (the autumnal equinox), the days will be found to decreaſe, and the nights to increaſe in length, till they come again to equality at *d*, and thence to the winter ſolſtice, where we ſet out.

Though we ſay the inhabitants within the arctic and antarctic circles are at oppoſite times of the year deprived of the ſight of the ſun, they are not altogether deprived of his light; for the atmoſphere reflecting and refracting the ſun's light (ſee Optics), forms a twilight, that reaches 18° below the horizon, and which is repreſented by the light ſhade, fig. 1, Plate XXXIV. Optics. Hence the day breaks to us when the ſun is ſtill 18° below the eaſtern horizon, as at *c*; and we have his light in the evening till he ſinks 18° below the weſtern, as at *p*. But as the ſun riſes conſiderably to the north of the eaſt, and ſets alſo to the north of the weſt with us, he both riſes and ſets ſo obliquely to the horizon, that twilight is much longer to the northern and ſouthern parts than to thoſe about the equator, where he riſes and ſets more perpendicularly.

Hence at midſummer Great Britain has no night; for even at twelve o'clock at night, the whole iſland is within 18° of the horizon, or boundary of the ſun's light.

It might be aſked, How we know that the earth makes an annual journey round the ſun? Through the ſhaft of a deep mine, we can ſee the ſtars in the day as well as night: through a teleſcope, properly equipt and ſituated, we alſo can ſee them: of courſe we can ſee the ſun and ſtars at the ſame time. Now if the ſun be ſeen near a fixed ſtar to-day, he will be ſeen conſiderably to the eaſt of it in a few weeks; and if the obſervations be continued through the year, we ſhall trace him round the heavens to the ſame fixed ſtar where we began to make the obſervation; proving, that he muſt have made a journey round the earth in that time, or the earth round him. As theſe two bodies do mutually attract each other, and that in proportion to their quantities of matter, it follows, from the laws of motion, that the ſmaller body muſt make out by motion what it wants in matter, and of courſe the earth performs the journey. For if two balls of unequal ſize were fixed on the two ends of a wire, fig. 5, Plate XL. and thrown up, ſo as to turn round each other, a centre of gravity, *a*, would take place between them, round which they would move; the ſmall one making out by its motion what it wanted in matter, and the large one making out by its matter what it wanted in motion: ſo the two circles, *b* and *c*, would be to one another exactly as the quantities of matter in the two balls.

It may alſo be aſked, How we know that the earth's axis keeps always nearly parallel to itſelf? This is alſo matter of ſimple obſervation. Every one knows, that there is one ſtar in the north which ſeems to be ſtationary, while all the reſt ſeem to turn round it, as round a centre; this is called the polar ſtar, and the earth's axis continually points towards it. Now if a circle turn round a centre, that centre may be conceived as without motion; ſo may the poles of our globe; and, of courſe, any body oppoſite to the north pole muſt appear to be ſtationary*.

But it may be ſaid, that the earth's axis does not point to the ſame part of the heavens at the two equinoxes, or the two ſolſtices. For if *s* be the polar ſtar, fig. 6, Plate XL. and the earth's axis at *a* point to it, ſurely, if that axis keep always parallel to itſelf, it does not point to that ſtar when it is at the equinoxes, or at *b* and *c*. Here we have an opportunity of contemplating the immenſe diſtance of the fixed ſtars, when we ſee that the diſtance *b c*, or the diameter of the earth's orbit (nearly 200 millions of miles), is not capable of affording any angle, or parallex, that the eye can perceive; nay, that it is but barely perceptible, aſſiſted by the niceſt inſtruments! The ſtar γ draconis, paſſes vertically over London nearly every twenty-four hours, and may be ſeen through a ſtraight chimney in the day; but when viewed by the zenith ſector, it is ſeen nearly in the ſame part of the field of the teleſcope at the vernal as at the autumnal equinox; becauſe the diameter of the earth's orbit bears ſo inſignificant a proportion to the diſtance of the fixed ſtars.

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* When we ſay the earth's axis points to what we call the polar ſtar, we do not ſpeak correctly true, for the axis points now above a degree on one ſide of it. Neither are we correct in ſaying the earth's axis inclines to the ecliptic 23½°, for that is ſpeaking of it in numbers; its mean inclination is about 27° 50′: beſides it has an annual nutation, being ſometimes more and ſometimes leſs than that, according to the inclination with which the protuberent part of the earth lies to the ſun, and the ſituation of the moon's nodes. It is alſo ſaid, that the inclination of the ecliptic to the equator is leſs by 23′ than it was in the time of Eratoſthenes, 276 years before Chriſt.

Of the Celeſtial Globe.—This globe is intended to repreſent the face of the heavens, as the other is that of the earth. The eye muſt conceive itſelf in the centre of this globe, and looking towards its concave ſurface, as we look to the concave arch of the heavens. Thus ſituated, and the globe rectified, if a ſmall hole was made through each ſtar, the eye would ſee through that hole the very ſtar in the heavens which that ſpot was made to repreſent: ſo exactly are the bearings and apparent diſtance of the fixed ſtars on the ſurface of this ideal concave repreſented on this globe! Aſtronomy is ſaid to have originated with the Chaldeans and Egyptians, people famous for their hieroglyphics and allegories. The conſtellations, or figures, on this globe, are of this kind; and no doubt had a reference to the myſteries of their religion, and the operations and appearances of nature. The heavens were an eternal book, open to all mankind, and therefore fit to regiſter ideas which they conceived to be moſt momentous. The Greeks were ſmitten with the grandeur of the conception; and crowded in ſeveral conſtellations that have an immediate reference to their fable. Modern aſtronomy has thought fit to continue theſe figures; as they afford an outline, or contour, that incloſes, as it were, a portion of the heavens: and by uſing the Greek alphabet in each conſtellation, every ſtar has a ſpecific name that diſtinguiſhes it from all others: ſo that if a comet, or any ſtrange appearance, occurred, theſe figures would afford the means of pointing it out, even to a correſpondent in China. The largeſt apparent ſtar in each conſtellation has the firſt letter of the Greek alphabet placed near it; the ſecond in magnitude the next, and ſo on. So, Aldebaran would be called α Tauri; Arcturus, α Bootis; the ſtar paſſing vertically over London, γ Draconis; and Pollux, β Geminorum, &c. Thus the ſtars may be ſpoken of as if each had a ſeparate name. But many ſtars having been diſcovered ſince theſe names took place, and becauſe a ſtar, which had one letter appropriated to it, was found to have ſeveral ſmaller ſtars near it, this method has been further enlarged by adding the ordinal numbers, 1, 2, 3, &c. to theſe neighbouring ſtars, as may be ſeen in the monthly occurrences of the Nautical Almanack.

Aſtronomers alſo divide the heavens into three regions—the northern, the ſouthern, and the zodiac. In the following table is contained the number of viſible ſtars in each conſtellation, their magnitudes, and thoſe ſelected for nautical obſervations.

Names of conſtellations, and the number of ſtars in each, according to Hevelius and Flamſtead.

ANCIENT CONSTELLATIONS.

		Hevelius.	Flamſtead.
Urſa Minor	Little Bear	12	24
Urſa Major	Great Bear	73	87
Draco	Dragon	40	80
Cepheus	Cepheus	51	35
Bootes		52	54
Corona Borealis	Northern Crown	8	21
Hercules		45	113
Lyra	Harp	17	21
Cygnus	Swan	47	81
Caſſiopeia	Lady in a Chair	37	55
Perſeus		46	59
Auriga	Waggoner	40	66
Ophiuchus	Serpentarius	40	74
Serpens	Serpent	22	64
Sagita	Arrow	5	18
Aquila	Eagle	23	71
Antinous		19	
Delphinus	Dolphin	14	18
Equulus	Horſes-head	6	10
Pegaſus	Flying-horſe	38	89
Andromeda		47	66
Triangulum	Triangle	12	16

		Hevelius.	Flamſtead.
Aries	Ram	27	66
Taurus	Bull	51	141
Gemini	The Twins	38	85
Cancer	Crab	29	83
Leo	Lion	49	95
Coma Berenices	Berenices Hair	21	43
Virgo	Virgin	50	110
Libra	Scales	20	51
Scorpius	Scorpion	20	44
Sagittarius	Archer	22	69
Capricornus	Goat	29	51
Aquarius	Water-pourer	47	108
Piſces	Fiſhes	39	113
Cetus	Whale	45	97
Orion	-	62	78
Eridanus	River	27	84
Lepus	Hare	16	19
Canis Major	Great Dog	21	31
Canis Minor	Little Dog	13	14
Argo Navis	Ship	4	64
Hydra	Monſter	31	60
Crater	Cup	10	31
Corvus	Crow	-	9
Centaurus	Centaur	-	35
Lepus	Wolf	-	24
Ara	Altar	-	9
Corona Auſtralis	Southern Crown	-	12
Piſces Auſtralis	Southern Fiſh	-	24

New ſouthern conſtellations.

		Stars.
Columba Noachi	Noah's Dove	10
Robur Carolinum	Royal Oak	12
Grus	Crane	13
Phœnix	-	13
Indus	Indian	12
Pavo	Peacock	14
Apus, Avis Indica	Bird of Paradiſe	11
Apis Muſca	Bee or Fly	4
Chamæleon	-	10
Triangulum Auſtralis	South Triangle	5
Piſces Volans	Flying-fiſh	8
Xiphias	Sword-fiſh	6
Tourcan	American Gooſe	9
Hydrus	Water-ſnake	10

HEVELIUS's *conſtellations, made out of the unformed ſtars.*

		Hevelius.	Flamſtead.
Lynx		19	44
Leo Minor	Little Lion		53
Aſterion and Chara	Greyhounds	23	25
Cerberus		4	
Vulpicula and Aſner	Fox and Gooſe	27	35
Scutum Sobieſki	Sobieſki's Shield	7	
Lacerta	Lizard	10	16
Camelopardalis	Camelopard	32	58
Monocerus	Unicorn	19	31
Sextans	Sextant	11	41

Many other vacancies in the heavens have been filled up with ſcientific conſtellations, viz. an air-pump, a clock, a teleſcope, a microſcope, a ſquare, a compaſs, an eaſel, gravers, a chemical furnace, ſhop of the ſculptor, &c. The croſs is a conſpicuous conſtellation in the ſouthern hemiſphere. The bull of Poniatowiſki, the ſceptre of Brandenburgh, and the harp, are alſo new; but the ſtars in all theſe have been enumerated in the old conſtellations, except thoſe too far to the ſouth to be ſeen by northern obſervers.

The number and order of the ſtars, capable of being ſeen by the naked eye, are,

Of the 1ſt magnitude	17
2d	63
3d	196
4th	415
5th	348
6th	341
Unformed ſtars	326
	1706

There are nine conſpicuous ſtars, near the ecliptic, and the moon's orbit, that are ſelected as proper ſtations to calculate the moon's diſtance from, both as ſhe approaches towards them, and as ſhe recedes from them; by which tables, in the Nautical Ephemeris, the longitude is found at ſea. Theſe ſtars are, α Arietis, Aldebaran, Pollux, Regulus, Spica, Antares, α Aquilæ, Fomalhaut, and α Pegaſi. Theſe ſtars are ſo near the moon's path, that her diſtance from one or other of them is calculated for every three hours of time, for many years to come. Let *a b*, fig. 8, Plate XLIX. repreſent the ecliptic; then may thoſe nine ſtars be eaſily diſtinguiſhed in the heavens, by their ſuperior brightneſs, and their proportional diſtances and bearings, as in the figure.

To the young aſtronomer, it muſt appear a little ſtrange, why the zodiacal conſtellations and their ſymbols ſhould not be together. The ſtars, for inſtance, that compoſe the ram, or Aries, are nearly 40° to the eaſt of the firſt point of Aries, or where the equator cuts the plane of the ecliptic, marked ♈; and the bull about the ſame diſtance from its ſymbol ♉; and ſo of the whole twelve ſigns, as they are called, of the zodiac. As the protuberance that ſurrounds the equatorial part of the earth, lies at all times obliquely to the ſun's attraction, except at the equinoxes, that part will be liable to a more powerful attraction than any other part of the earth; by which the equatorial obliquity is drawn more and more towards a level, at the rate of about half a ſecond per year.

But I conceive the ſun's attraction of the earth to be balanced by the repulſion of his light, at their medium diſtance; and, therefore, that the ſouthern hemiſphere, *s*, fig. 4, Plate XLI. will be more repelled at our winter ſolſtice, than the northern hemiſphere, *n*, at the ſummer ſolſtice; as the earth, at that time, is above its medium diſtance from the ſun, as in winter it is within it. Hence the unequal repulſion againſt the two hemiſpheres, and the tendency which the ſun's attraction has to draw the equatorial protuberance out of its oblique ſtate into a more parallel one, has altered the inclination of the earth's axis, ſo that it is one third of a degree more perpendicular to the plane of the ecliptic than it was in the days of Ptolemy: in his time it inclined 23° 48′ 45″ from that perpendicular; in our time, 23° 27′ 56″. (See Lecture Firſt.) Hence ♈ changes its place backward (or contrary to the order of the ſigns) 50″ every year, and the plane of the earth's equator croſſes the ecliptic 20′ in time ſooner every year: therefore, the equinoctial point ♈ goes back in the ecliptic one degree in 72 years, and occaſions the diſagreement of the zodiacal conſtellations, with the ſymbols that repreſent them. This makes a ſenſible difference in the latitude and longitude of the ſtars; and it becomes neceſſary to reviſe celeſtial globes and atlaſes every 72 years. The ſigns of the zodiac are ſymbolical of the ſeaſons. The ſun is ſeen in the Ram and Bull in the fructifying ſeaſon of ſpring. The crab is ſaid to crawl backward; and the ſun begins to withdraw from us when he paſſes through Cancer. He is ſeen in Leo in the dog days; the fierceneſs of his rays is repreſented by a lion. Virgo has an ear of wheat in her hand, as an emblem of harveſt: and the Balance beautifully repreſents the medium between the heat of ſummer, and cold of winter; of long and ſhort days, &c. &c. Thoſe ſigns are numbered in this ſingular way:

Aries	♈	0 ſign.	Libra	♎	6th ſign.
Taurus	♉	1ſt.	Scorpio	♏	7th.
Gemini	♊	2d.	Sagittarius	♐	8th.
Cancer	♋	3d.	Capricornus	♑	9th.
Leo	♌	4th.	Aquarius	♒	10th.
Virgo	♍	5th.	Piſces	♓	11th.

Each of theſe ſigns is divided into 30°, and each degree into 30 minutes, and each minute into 30 ſeconds: ſo that the ſituation of the ſun, on the 10th of May, would be ſaid to be in 1s. 20° 0′, or the 20th degree of the firſt ſign. Jupiter in 3s. 23° 9′ 12″, would be read that Jupiter was in the 23° 9′ 12″ of the 3d ſign, &c.

The ecliptic being the path in which the earth travels through the heavens, it neceſſarily becomes the moſt important line on the celeſtial globe: longitude is counted *upon it*, from the firſt point of ♈; and latitude is counted *from it*, north or ſouth. It is in the middle of a zone, or belt, of 16° wide, called the zodiac, and which includes the latitudes of all the planets: beyond this limit, north or ſouth, the moon or any of the planets never move. The moon never departs from the ecliptic further than 5° 20′, nor Mercury more than 7°. The ecliptic is croſſed by four lines, at the four cardinal points of the heavens: thoſe in the equinoctial points are called *equinoctial colures*; and thoſe paſſing through the parts where the ecliptic touches the tropics, the *ſolſtitial colures*. It is alſo croſſed by meridians, which all meet at the two poles of the ecliptic. On theſe meridians is counted the latitude of the fixed ſtars, which is their diſtance from the neareſt part of the ecliptic; and what that part is diſtant from the firſt point of ♈, is called their longitude.

The *declination* of a ſtar, is its diſtance from the celeſtial equator. The latitude, therefore, of Arcturus, is 31° north; its longitude, 202°; and its declination, 20° north.

The *right aſcenſion* of the heavenly bodies is their diſtance from the firſt point of ♈, eſtimated in time on the equator. The earth turns 15° of a circle every hour, therefore the meridians are placed

15° from each other, for the eaſy counting of time; and hence the equator is divided into 24 hours. If a globe be made into a direct ſphere, by bringing its poles into the horizon, and a ſtar be brought to the eaſtern horizon, the place where the equator is cut by it will ſhew the right aſcenſion in time. Thus the right aſcenſion of Arcturus is fourteen hours and five minutes.

Oblique aſcenſion of a ſtar is an arc of the equator, reaching, according to the order of the ſigns, from ♈ to that point of the equator that riſes with the ſtar, in an oblique ſphere: and the difference between the right and oblique aſcenſion of a ſtar is called its *aſcenſional difference.*

Time is meaſured by the apparent motion of the ſun round the earth, and round the heavens: the time from his leaving any particular meridian, till his return to it again, is divided into 24 hours, and called a day; and the time from his leaving any fixed ſtar, till his return to it again, is a year. The civil day is reckoned from midnight to midnight; but the aſtronomical day begins 12 hours later, and is from noon to noon, or the interval between two ſucceſſive tranſits of the ſun over the ſame meridian. This day is not divided into two twelves, as the civil day; but goes on from one to twenty-four uninterruptedly; ſo that 18 hours of aſtronomical time would be 6 next day. But though the ſun ſeems to go round the earth in 24 hours, the ſtars ſeem to go round it in $23^h\ 56^m\ 4^s$; ſo that they gain $3^m\ 56^s$ upon the ſun every day, which amounts to one day in one year. This ariſes from the annual motion of the earth round the ſun; which makes him appear to *ſhift* forward through the ſigns, nearly a degree every day; and therefore if a ſtar was on the meridian with him to-day, I ſhould find him nearly a degree to the eaſt of it to-morrow, and my meridian would croſs the ſtar nearly four minutes ſooner than it would croſs the ſun: the firſt of theſe is called a ſidereal day ; the latter, a ſolar day. Fig. 3, Plate XLII. will render this familiar. S, is the ſun : 1, is the earth, in a poſition where the ſun and the ſtar *d* would both croſs the meridian *a c* at the ſame time ; but when the earth has arrived at poſition 2, it will be ſeen that the meridian, *a c*, will come to the ſtar *d* ſooner than to the ſun, by the diſtance *o c* : when the earth comes to 3, the difference will be ſtill greater ; and when it arrives at 4, there will be a quarter of a circle difference, as from *o* to *c*, or a quarter of 24 hours, i. e. the ſtar will croſs the meridian ſix hours before the ſun. At this place, it may ſeem as if the plane of the meridian, *a c*, did not point to the ſtar *d* : this ariſes from the immenſe diſtance of the fixed ſtars ; in compariſon of which, the whole diameter of the earth's orbit may be conſidered merely as a point. At 5, the diſtance *o c* continues to increaſe ; and at 7, the ſtar would be on the meridian 12 hours before the ſun. This increaſe continues till the earth arrives at 1, where it ſet out ; ſo that the ſidereal year would contain one day more than the civil year. For if the ſun and ſtar were on the meridian at twelve o'clock, at No. 1, the ſtar at No. 2, would croſs it at ten ; at No. 3, at eight ; at No. 4, at ſix, &c. &c. &c. : ſo it is found, that the earth travels round the ſun, from any fixed ſtar, to that ſtar again, in $365^{d}\ 6^{h}\ 9^{m}\ 14^{s}.5$. But this ſidereal year differs from the tropical year (on account of the preceſſion of the equinoxes) $20^{m}\ 29^{s}$; for the time that the ſun is in paſſing from either of the ſolſtitial or equinoctial colures to the ſame point again, is $365^{d}\ 5^{h}\ 48^{m}\ 45^{s}\ 5^{ths}$. The civil year, therefore, conſiſting of $365^{d}\ 6^{h}$, is nearly a medium between the ſidereal and tropical years.

It is found, that a well-going clock and a ſun-dial do not go together; but that the ſun is ſometimes faſter than the clock, and ſometimes ſlower. There are two cauſes to produce this effect; 1ſt, the obliquity of the equator to the plane of the ecliptic; and 2dly, the oval orbit of the earth, which makes it farther from the ſun at one part of the year than another. Let ♈ ♋ ♎, and ♑, fig. 1, Plate XLII. repreſent the ecliptic; and ♈ ♎, the equator: and let us ſuppoſe the ſun moving in the ecliptic from ♈ to *c*; while a ſtar, or another ſun, moves from ♈ to *d*; and that the earth moved within this ſphere of celeſtial meridians, *x* ♈ *z* ♎. Now, as the ſun moves obliquely in the ecliptic, and the ſtar directly in the equator, a meridian of the earth, *n m*, would cut the point *c*, before the point *d*; though they are equally diſtant from the point ♈, from whence the ſun and ſtar ſet out; ſo that, as the ſtar repreſents the clock, it is evident the ſolar noon would be before that of the clock: at *d s* the obliquity would be ſtill greater; but at ♋ ♑, the ſolſtice, the quadrants coincide, the ſun and ſtar are in the meridian, and cut it at the ſame time. In the quadrant between ♋ ♎, it is equally evident the meridian *t y* would come to the ſtar *f* ſooner than to the ſun *t*; ſo that the clock would be before the ſun from midſummer to the autumnal equinox, when they would again be together. From ♎ to ♑ the ſun would be before the clock; and from ♑ to ♈ the clock before the ſun.

Theſe differences may be familiarly ſeen on a celeſtial globe; where, if a forefinger nail be placed 15° from ♈ on the ecliptic, and another 15° from ♈ on the equator, and the globe turned, that on the ecliptic will arrive at the meridian before the other, though their diſtances are the ſame. Any other two equal diſtances on the ecliptic and equator will meet the meridian exactly agreeable to what has been ſaid on fig. 1, Plate XLII.

But the inequality of the ſun and clock does not altogether ariſe from the obliquity of the ecliptic. The ſun himſelf is not equal in his motion all the year. (Aſtronomers commonly ſpeak of the ſun as if he had motion; but it is the motion of the earth that ſhould be underſtood.) The orbit of the earth is an ellipſis, and the ſun may be conſidered as fixt in one of the foci of it. To make an ellipſe mechanically, we ſtick two pins in a table, and tying the two ends of a thread together, lay it over the pins; then ſtretching it round them with a pen, or pencil, an ellipſe will be made, and the place of the pins will be the foci; and S, fig. 2, Plate XLII. will thus be the centre of the ſun. When the earth is at *a*, its neareſt diſtance from the ſun, the ſun is then ſaid to be in *perihelion*; and when at *b*, its greateſt diſtance, the ſun is in *aphelion*. Now, as it deſcribes equal areas in equal times, and the ſpace *c* S *d* is equal to the ſpace *e* S *g*, it follows, that the earth will move from *c* to *d* in the ſame time it would move from *g* to *e* (when at its greateſt diſtance, and partaking of the ſun's attraction ſo much leſs). Let us ſuppoſe that it travels from *c* to *d* in one day; then would the meridian *m* deſcribe the cycloid *m n* in that time. But the ſtar *s*, being on the meridian with the ſun, when we ſet out from *c*, would become parallel, and point to *s* when it came into the directions *q r*; for *q r* is parallel to *m o*: therefore the earth muſt turn from *q*, the end of the ſidereal day, to *n*, the end of the ſolar day; and the arch *q n* would ſhew the difference of their lengths to be much greater than at the oppoſite time of the year. Call the diſtance *g e* one day's journey when the ſun is in apogee, or middle of ſummer, and the ſtar *x* on the meridian with the ſun S; then would the meridian *z* deſcribe in ſpace the cycloid *z p* in one ſolar day: but that meridian would cut the ſtar *x* before it came to *p*; for the meridian *w u* is parallel to *z x*. But here it muſt be obſerved, how much ſmaller the arch *u p* is than *n q*; and, of courſe, how much nearer ſolar and ſidereal time approach to each other in ſummer than in winter. But if ſolar and ſidereal time could be reduced to equal time, all the celeſtial motions, and all duration, would be reduced to one ſtandard. This is an object of ſuch importance in aſtronomical computations and obſervations, that it is calculated for every day through the year, and for many years to come, in every ephemeris of conſequence in Europe. The theory of this reduction may be underſtood by the diagram, fig. 4, Plate XLII. A B C D repreſent the ecliptic or orbit of the earth; or, which is the ſame thing, that through which the ſun ſeems to paſs in one year. Therefore the earth is placed at E, and the ſun in apogee at A, as he is a few days after he has paſſed the ſolſtice at ♋. The ball, or ſtar, *a*, is to be ſuppoſed moving round the circle in which it is placed with a perfectly equal motion. The ſun and this ſtar are at preſent together; but as the ſun is in that part of the orbit where his motion is the ſloweſt, the ſtar will leave him, and arrive at *b*, at the time the ſun is only at H. But as the ſun's motion is now accelerated, he will overtake the ſtar at C, and paſs it before he arrives at K; for he is now in perigee, and moves ſo ſwift as to perform that half of his annual journey from ♎ to ♈ in eight days leſs time than the half from ♈ to ♎. Hence the reaſon why our ſummer half-year is eight days longer than the winter half-year. The conjugate, or longer, diameter of the elliptic orbit A E C is called the line of the apſides*; and ſo far as the ſun has departed from A, his

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* This diameter *conjoining* the aphelion and perihelion points in a line paſſing through the centre of the orbit of a planet; to which the apogee and perigee correſpond between the moon and the earth.

apogee is called his mean *anomaly* (or *inequality* at any intermediate diſtance between the two points), whether it is at H, or B, or C, or D, &c. So if he were at *z*, 130° from his apogee at A, he would be ſaid to be four ſigns and ten degrees from it, which is his mean anomaly; or if he were at *y*, 310° from the apogee, his mean anomaly would be ſet down as ten ſigns and ten degrees. Hence it appears, that when the ſun's anomaly is leſs than ſix ſigns, the ſun will be before the clock, which is repreſented by the equal-moving ball, or ſtar, *a* and *b*; and when the ſun's anomaly is more than ſix ſigns, the clock noon will precede the ſolar noon; and they will be together at the apogee A and perigee C. By the unequal motion of the ſun, we find there are but two parts of the year in which the ſun and an equal time-keeper can be together; but by the obliquity of the ecliptic, there were four times in the year when the ſun and clock would be together: the real equation of time muſt, therefore, be compounded from theſe two cauſes of inequality: and what adds to the difficulty of the calculation is, that the line of apſides does not coincide with the line of the ſolſtices; i. e. the apogee is nine degrees from it, viz. in the ninth degree of Cancer; and the perigee in the ninth degree of Capricorn.

The equation of time being calculated for every day in the year in the Nautical Almanack, and *Connoiſſance de Temps*; and placed alſo on the horizon of common globes for the ſecond year after leap-year; a table here would be ſuperfluous.

Reaſon of the Biſſextile or Leap-year.—It is natural to ſuppoſe, that in the early ages of the world the length of the year muſt be very imperfectly laid down: the firſt attempt, that had any pretenſions to accuracy, was made by Julius Cæſar, who fixed its length at $365^{d}\ 6^{h}$: this was too much; for as the real time that the ſun goes from a tropic to that tropic again is $365^{d}\ 5^{h}\ 48^{m}\ 48^{s}$, there would be $11^{m}\ 15^{s}$ overplus every year. In 1800 years this amounted to eleven days, which, in England, was taken out of the month of September, in the year 1752. A ſimilar reform had taken place in moſt parts of Europe, under the auſpices of Pope Gregory, in the year 1582. Our civil year of $365^{d}\ 6^{h}$ is ſtill wrong; but, for the ſake of eaſy reckoning, we call it no more than 365 days; and letting the ſix hours accumulate for four years, add one day at that time to the end of February, which brings all tolerably ſtraight again. Suppoſe the earth touched the tropic at *a*, fig. 1, Plate XLIII. and the year begun at that time; and ſuppoſe that in 365 days the earth had come ſhort of the place where it ſet out, and got no farther than *b*; at *b* the next year commences: but the earth cannot get round its orbit to *b* again in 365 days; ſuppoſe no further than *c*; at *c*, then, the next year commences, and will end at *d*. Is it not evident, by ſuch reckoning, we ſhould, in time, have ſnow in June, and roſes at Chriſtmas? But the ſix hours ſo loſt every year, in four years amount to a day; which, being added to the end of February, brings *d* back to *a*, and the year commences pretty near its right place.

END OF THE FIRST LECTURE ON ASTRONOMY.

LECTURE XI.

ON THE MOON.

As the moon is our own particular ſatellite, we are more intereſted in the knowledge of her character and properties, than of any other of the heavenly bodies, except the ſun and our own planet. We do not conſider this luminary as a primary planet; ſhe is a mere ſatellite, or an attendant on the earth; ſhining by no light of her own, but borrowing her light from the ſun, ſhe reflects a portion of it to us, as any poliſhed body would the light of a candle. Not that ſhe is a poliſhed body, for with the moſt ordinary teleſcope we can ſee her face covered with more inequality than our earth;—long ranges of mountains, and numberleſs round pits that look like the craters of extinguiſhed volcanos. With the naked eye we can ſee dark and light ſhades upon her, and which, through a teleſcope, look like land and water; for land will reflect the light of the ſun much more than water; and the aeronauts, when high in our atmoſphere, obſerved that our ſea appeared more black and dark than the land.

The anomalies of this ſatellite, ariſing from the action of the earth and the ſun upon her, conſtitute the moſt difficult problems in-the ſcience of aſtronomy: the motion of the nodes, *contrary to the circuit in which ſhe revolves*; the motion of her elliptic orbit in reſpect to its apogee and perigee, *in a contrary direction to the nodes*; her varied and complex velocities in different parts of her orbit, and at different parts of the year; her face being always towards the earth, and other minute irregularities, preſent a perplexity and difficulty of calculation, that almoſt require ages of obſervation and calculation to aſcertain the true phenomena of her motions.

A body borrowing its light from another, can only be enlightened on one ſide at a time; therefore, as the moon revolves round our earth in about twenty-nine days and a half, ſhe muſt ſhew us ſometimes more, and ſometimes leſs, of her light ſide in that journey; and hence the phaſes, or different appearances, ſhe aſſumes in one lunation. Let S, fig. 2, Plate XLIV. repreſent the ſun; *m*, the moon; and E, the earth. In this ſituation the moon will have her dark ſide turned towards the earth; and, if ſhe can be ſeen, ſhe will appear of a faint greyiſh colour, and ill defined, as *a*. This ſituation is called the change of the moon. Proceeding towards *n*, ſhe becomes a creſcent, and is called the new moon; for a ſpectator, *u*, after ſeeing the ſun ſet beneath the weſtern horizon, *u*, *w*, would ſee the moon a little above it; and peeping under her, as it were, would ſee a little ſlip of the enlightened ſide, as at *b*. Proceeding on her monthly journey eaſtward, we now ſee her at her firſt quarter, and a half-moon, as ſhe appears at *c*: for now ſhe is almoſt at the meridian when the ſun ſets at *u w*. As the moon frequently riſes and ſets in the courſe of a ſingle night, this might appear like a real motion. But no: it is the motion of the earth on its axis from weſt to eaſt, that makes her appear to move from the eaſt towards the weſt; her real motion is from the weſt towards the eaſt (the ſame way the earth turns on its axis), ſo that if we ſee her near any particular fixed ſtar to-night, we ſhall ſee her about thirteen degrees to the eaſt of that ſtar the next night, and ſo on. A few days after her firſt quarter, we ſhall find her at *p*: the ſpectator at *u* now looks at her almoſt in the ſame direction as the ſun, when he ſets; and, therefore, ſees the greateſt part of her enlightened face gibbous, or approaching to a circle. Almoſt fifteen days after her change, we find her at the full at *q*: now when the ſun ſets in the weſt at *w*, ſhe riſes in the eaſt at *e*, and has performed half of her monthly circuit round the earth. A few days after this ſhe arrives at *r*, and becomes gibbous again, diminiſhing from her circle; for now a portion of her dark ſide appears oppoſite the ſun: and at *s* ſhe is again a half-moon, and is ſaid to be at her third quarter. In this ſituation, when the ſun ſets, ſhe is on the other ſide of the earth to the ſpectator *u*; ſo that the earth muſt turn from *u* to *z* before the ſpectator can ſee the moon riſe, which will be about twelve or one in the morning. When ſhe arrives at *t*, a conſiderable portion of her dark ſide is turned towards the earth, and but a ſmall part of her enlightened ſide can be ſeen, as at *h*; for now ſhe riſes but a little before the ſun, and is again a creſcent, but with the thick part of it turned to the eaſt, as it was to the weſt when ſhe was a new moon. In a few days after this, ſhe again meets the orient ſun, and diſappears.

This is her ordinary monthly appearance, which may be naturally imitated by walking round a white ball when the ſun ſhines upon it; thoſe phaſes will then appear on the ball, as in nature.

Lunar Eclipſes.—If the moon moved round the earth, on a level with the ecliptic, or, in other words, in the plane of the earth's road round the ſun, ſhe would eclipſe the ſun every time ſhe came to the change; and be herſelf eclipſed every time ſhe comes to the full: for an eclipſe of the ſun is occaſioned by the dark body of the moon paſſing between the earth and the ſun; and a lunar eclipſe by the moon paſſing through the ſhadow of the earth, and thereby loſing her borrowed light. But the moon moves in an orbit that is oblique to that of the earth; one half of it being on the north ſide of the ecliptic, and the other on the ſouth; ſo that it croſſes the earth's road in two points, which are called her nodes, making with it an angle of 5° 18′: ſee fig. 5, Plate XLIII.; where *n m* is the ecliptic, and *c d* the moon's orbit; *a* the aſcending node (generally marked ☊), where ſhe riſes to the north, and *b* the deſcending node (generally marked ☋), where ſhe paſſes to the ſouth, of the ecliptic.

Now, though this orbit is a trackleſs path, that has no more ſubſtantial exiſtence than the circle I make in the air with my hand, it performs a regular circuit round the zodiac retrograde, or contrary to the order of the ſigns, every eighteen years and 225 days; i. e. the node, or interſection, *a*, will in a year be removed to *e*, and the oppoſite node to *f*. In another year the aſcending node will have gone back to *z*, while the deſcending node will cut *y*, &c. Hence when the moon is in the upper part of her orbit, *c*, ſhe would be ſeen from the earth above the ſun, and when in the lower part, *d*, below him: ſo that an eclipſe could not happen but when the nodes lie in a line, or nearly ſo, with the ſun and earth; as *a b*, fig. 3, Plate XLIII. This figure repreſents both a ſolar and lunar eclipſe: at *c* the moon eclipſes the ſun; and a ſpectator on the earth at *e* would, for a few minutes, have the whole diſk of the ſun covered by the moon, For though the moon is a point in compariſon of the ſun, her nearneſs to us makes her commonly ſubtend as great an angle in the eye; and ſhe therefore appears as large. But as her orbit is an ellipſe, as well as that of the earth, and as its line of apſides is continually going forward in the order of the ſigns, ſo as to make a circuit round the zodiac in nine years, ſhe ſometimes eclipſes the ſun when ſhe is in apogee, and ſometimes in perigee, and ſometimes at her mean diſtance.

To give a clearer idea of the motion of the nodes and apſides, let fig. 1, Plate XLVI. repreſent the earth and the moon's orbit; E the earth, B the moon's orbit; then will 1, 2, 3, 4, 5, 6, &c. ſhew the places of the moon's nodes for the nineteen years that they are in making a circuit round the ecliptic, and in a contrary direction to the motion of the moon, which is from weſt to eaſt, while the nodes move from eaſt to weſt. The motion of the apſides (or the moon's apogee as it is often called) is in the ſame direction as the motion of the moon, viz. from weſt to eaſt; and the nine years in which it performs its circuit round the heavens is repreſented by thoſe ſpots marked *a*, *b*, *c*, *d*, *e*, &c. The twelve diviſions marked ♈, ♉, ♋, &c. are the twelve ſigns of the zodiac. The direction of the nodes, apſides, and ſigns, are denoted by the alphabetical direction of the letters, and the progreſſive direction of the figures. Theſe motions are ingeniouſly repreſented by a machine invented by Mr. Ferguſon, called his Paradox.

She is in perigee, fig. 3, Plate XLIII. at *c*, where her central ſhadow reaches the earth: but were ſhe in apogee, and farther from the earth, her central ſhadow would not reach it; her diſk would appear leſs than that of the ſun, and, of courſe, a ring of his light would, to the ſpectator at *e*, appear round the dark body of the moon, and the eclipſe would be called annular, from being like a ring. It is evident that the ſhadow of the moon on the earth would cover but a ſmall part of it, ſo that ſolar eclipſes are very local, and ſhort in duration; for the ſhadow paſſes like that of a cloud over the earth, at the rate of 2000 miles an hour; but lunar eclipſes may be ſeen by a whole hemiſphere at once.

When the moon therefore changes at her leaſt diſtance from the earth, her dark ſhadow covers but a ſpot on the earth of about 170 miles broad, if the time be about noon; but much more if the time be in the morning or evening, from the ſhadow falling obliquely on the earth. To all who are within this ſpot the ſun will appear totally eclipſed for about five minutes, but to no place without it, although he will be partially eclipſed for ſeveral hundred miles round, as may be ſeen by a perſon ſituated at *n*, fig. 6, Plate XLIII. who would ſee three digits of the ſun eclipſed along the line *n m*.

When the moon changes at her *mean* diſtance from the earth, the point of her ſhadow but juſt reaches it, as *q*, fig. 6, Plate XLIII.; and to the places where the ſhadow paſſes ſucceſſively over, the ſun will be totally eclipſed only for an inſtant of time.

When the moon changes in apogee, or at her greateſt diſtance from the earth, ſhe appears like a black patch on his face, and his radiance ſurrounds her like a ring, and therefore the eclipſe is called annular.

Frequently a fortnight after a ſolar eclipſe, we have a lunar one, if the line of the nodes, *a b*, be not removed out of the earth's ſhadow in that time. The moon firſt dips into the penumbral ſhadow at *z*, and continues very viſible, till ſhe arrives at the central ſhadow, when ſhe aſſumes a copper colour, and is almoſt invisible; ſhe then enters the other ſide of the penumbral ſhadow, and makes her exit at *n*, being about three hours in the whole paſſage. It might be ſuppoſed when ſhe was in the middle of the ſhadow, and diveſted of her borrowed light, ſhe muſt be inviſible. This is not the caſe; for the earth's atmoſphere will refract, or bend, the rays inward that paſs through it, at *r* and *q*, ſo much into the earth's ſhadow, as to throw a few on the moon in the direction *r f* and *q f*, and render her ſtill viſible.

There is alſo a penumbra in a ſolar eclipſe as well as the central ſhadow, repreſented by the light ſhade round the conical one, fig. 20, Plate XLIII. which gives a ſtriking proof how very large the ſun is in compariſon of the earth. The dark ſhade *n o* is the track made by the central ſhadow over the earth; ſo that after the ſhadow has paſſed from *n* to *q*, a ſpectator at *n* would ſee the moon leaving the ſun along the ſpotted line *n m* (while the ſpectator at *q* would obſerve a total eclipſe). If he were nearer the centre of the penumbra, he would have more of the ſun's face cut off by the moon. So that, the diameter of the ſun (in every direction) is ſuppoſed to be divided into twelve digits, as may be ſeen by the line *z q*, and three digits are eclipſed to the ſpectator *n*, on the ſun's diſk; and if the eclipſe ended at *q*, would be ſaid to end 90° from a line paſſing perpendicularly through the ſun's centre. Solar eclipſes begin and end well defined as to time; but the earth's ſhadow is ſo faint, that it is difficult, even with a good teleſcope, to aſcertain the time when an eclipſe of the moon begins or ends.

When the moon at full is a little diſtance from the node, ſhe may yet ſuffer a total eclipſe; becauſe the earth's ſhadow is ſo much more in diameter than ſhe. Let *a b*, fig. 1, Plate XLIV. be the plane of the ecliptic, in ſome part of which the earth's ſhadow will always be. Let a ſection of that ſhadow be *c*, *d*, and *e*; and let *r s* be a part of the moon's orbit. If the moon is full at *c*, ſhe will paſs through the upper part of the ſhadow, and be but partially eclipſed. But when ſhe is full in the node, as at *d*, that node muſt be in the middle of the ſhadow, and ſhe will paſs directly through it, and be totally eclipſed. So when the ſhadow is beyond the node, as at *e*, and the moon is at full there, ſhe will paſs through the lower part of the ſhadow, and be only partially eclipſed. But when ſhe is at full at *z*, ſhe would ſteer clear of the ſhadow, and not be eclipſed at all. This ſhews the limits of eclipſes to be only near the node; and, by obſervation, it is found that a ſolar eclipſe cannot happen at a greater diſtance from the node than eighteen degrees; nor a lunar eclipſe at a greater diſtance than twelve degrees. An eclipſe of the moon always begins on her eaſtern ſide, and goes off on her weſtern; that of the ſun on the weſt, and ends on the eaſt ſide, to an European obſerver.

As ſolar and lunar eclipſes can only happen at the change and full of the moon; and as the nodes go backward at the rate of 19° 1′ a-year; which, together with the annual change in the moon's apſides, render the exact calculation of eclipſes a difficult problem; yet a tolerable gueſs may be thus formed. The above 19°½ anſwer pretty nearly to 19 days of the ſun's motion; the half of which being taken from half a year (viz. 9½ from 182½ days), leaves 173 days, the time of the ſun's conjunction with one node, to the time he will be in conjunction with the other. Now, as degrees of the ſun's motion anſwer nearly to days (for there are 360 degrees performed in 365 days), it is plain there muſt be an eclipſe of the ſun whenever the moon changes within eighteen days before or after the ſun's conjunction with either of the nodes; and that the moon muſt be eclipſed whenever ſhe is full within twelve days before or after the ſun's conjunction with either of the nodes. The place of the moon's nodes may be found in moſt almanacs, and thereby at what new and full moons there muſt be eclipſes.

As the ſun paſſes through each node but once in the year, it is evident we can but have two capital eclipſes of the ſun and moon in one year. In ſome years there are but two, and both of the ſun: there have been ſix in one year, four of which were of the ſun; but theſe are ſeveral of them partial and inviſible.

We generally ſay that nineteen years is the great period of the moon, and that at the end of that time ſhe comes into the ſame part of the heavens with the ſun ſhe was at the beginning of it; and from thence begins a reſtitution of all their eclipſes. This is not ſtrictly true. In making 223 revolutions the moon comes in conjunction with the ſun, and the node from whence they ſet out: but this takes place in 18 years 11 days 7 hours and 43½ minutes; and therefore, if that time be added to the mean time of any eclipſe, we ſhall have the mean time of the return of that eclipſe. So that any one in poſſeſſion of a ſet of almanacs for nineteen years, may eaſily calculate the time of any future eclipſe, allowing for the odd hours which, every four years, make leap-year.

It is a curious fact, that the time from the middle to the end of an eclipſe, is always longer than from the beginning to the middle. May not this be occaſioned by the impulſe of the earth's centrifugal light; which, co-operating with the ſun's attraction, accelerates the approach to, and retards the departure from, the middle? And as the moon when eclipſed is at that time deprived of the ſun's impulſive light, is it not agreeable to the known laws of motion, that being for a time deprived of the cauſe of her motion, ſhe moves in the latter part of the eclipſe only by her vis inertia, or the quantity of motion ſhe had acquired before ſhe was deprived of the ſun's light? And may not the irregularity of the moon's motion about the change, be alſo occaſioned by the reaction of the earth's light againſt that of the ſun, in conjunction with the diſturbance ſhe meets with there by the ſun's attraction? And as one-half of her monthly period is performed on that ſide of the earth which has no light to throw off, muſt there not be a diſparity in the attraction and repulſion, which I apprehend to be the cauſe of her motion; and may not this produce her elliptic orbit, the receſſion of her nodes, and the revolution of her line of apſides? But there are ſo many irregularities in the moon's motion, that it is ſaid to require above forty geometrical theorems and calculations to aſcertain them. One would naturally ſuppoſe that when the moon has paſſed the full, and is then attracted both by the earth and ſun in nearly the ſame direction, that her motion would be ſo accelerated that ſhe would move faſter from the full to the change, than ſhe would from change to full: but this is not ſtrictly the caſe when ſhe changes in perigee; in this ſituation, for the ten days before ſhe arrives at the change, there is 8 hours and 54 minutes difference of time of her paſſing the ſame meridian: but on her return from her change in perigee, for ten days following, that difference is 10 hours and 3 minutes; conſequently her motion from the ſun is ſwifter than her approach towards him. This may be better underſtood by fig. 2, Plate XLVI. Let E be the earth, S the ſun, G the moon's orbit, and *a* its apogee, and *p* its perigee. Let the moon, *p*, begin her courſe from the change in perigee, or from the left hand towards the right; and let *c* be the meridian of any place turning with the globe the ſame way. Now, while the earth has turned once round upon its axis, the moon has travelled from 60 to 65, and the meridian *c* muſt turn 65 minutes more before it will paſs her; of courſe 65 minutes later than it paſſed her the day before. In another day ſhe arrives at 67, and the meridian *m* will paſs her 67 minutes later than it paſſed her the day before, ſo that her motion now is very ſwift. When ſhe gets to 64, the meridian will croſs her 64 minutes later than the day before, &c. Hence the hour and minute is ſhewn by the inner figures, as $1^h\ 5^m$, 2, 12, &c.; and the figures on the outſide of the moon's orbit, how many minutes the meridian is later every ſucceeding day in paſſing her. It may be perceived that her motion from the ſun is ſwifter than towards him; for in her deſcent towards him from the full at *a* towards *k*, ſhe is but 50, 46, and at one place but 40 minutes later than when croſſed by the meridian the preceding day. The moon is 29 days 12 hours and 44 minutes in going from a change to the change again, which is her ſolar or ſynodical revolution; but in going from a ſtar to that ſtar again ſhe is 27 days 7 hours and 43 minutes, which is called her ſidereal or periodical revolution: the difference of which periods ariſes from the motion of the earth round the ſun, which makes that luminary ſeem to travel round the ecliptic at the ſame rate as the earth *really* does; hence in the time of one revolution of the moon, the ſun ſeems to have gone forward in the ecliptic near a twelfth part of his apparent annual journey, ſo that the moon muſt go farther than round the heavens before ſhe can overtake him, and come to her change; this takes up 2 days 5 hours and 1 minute, the difference of time in which a ſynodical and ſidereal revolution of the moon is made: hence when the moon is full at *a*, ſuppoſe at twelve at night, and on the meridian, it will be 43 minutes paſt twelve the next night before ſhe paſſes the meridian, and 51 minutes after 43 minutes paſt twelve when ſhe croſſes the meridian the next night, &c. ſo that the figures round the figure denote the difference of time between the minute ſhe paſſed the meridian one day, and the minute ſhe paſſed it the preceding day, &c. and hence may be ſeen how much ſlower ſhe moves from *a* by *k* to *p*, than from *p* by *z* to *a*. Theſe figures denote the *real* difference of time between the moon's paſſing the meridian from day to day, that is, when ſhe changes in perigee; but when ſhe changes in apogee theſe intervals are very different; for eight days before the change, the *whole* difference of time between her croſſing the meridian each ſucceeding day amounts to 6 hours and 20 minutes; but in receding from the change it amounts to 5 hours and 50 minutes, in eight days: this may be underſtood by a reference to fig. 3, Plate XLVI.; where E is the earth, S the ſun, *m* the moon, and O her orbit. Here the moon *m* changes in apogee (or in the moſt diſtant part of her orbit from the earth), and different from her change in perigee;—ſhe is *accelerated* in her deſcent towards the ſun from the full at O, by *s* to *m*; and *retarded* from the change *m* by *x*, to the full at O: the figures (as in the 1ſt diagram) denoting the number of minutes that the moon paſſes the meridian later every ſucceeding day. In both theſe diagrams, the numbers are deduced from the lateſt and moſt accurate obſervations.

May not this acceleration and retardation of the moon's motion in theſe two important ſituations of her orbit be accounted for from the principles of attraction and repulſion? In the firſt diagram the moon is full in apogee, at *a*; may not that diſtance from the earth and ſun be the cauſe why her motion is ſo ſlow, that ſhe croſſes the meridian only 43 minutes later than ſhe did the day before?—As ſhe approaches nearer the earth and ſun, that ſhe ſhould be accelerated according to the numbers 51 and 52?—That towards her third quarter ſhe ſhould again be retarded by the ſun's repulſive ſtream, acting againſt her motion according to the numbers in the diagram, 48, 47, 46, 44, and 40?—And that her approach to change in perigee, ſhould again accelerate her motion, as ſhe comes nearer and nearer to the earth, and partaking more and more of its attraction, ſo as not only to overcome that attraction in the point of perigeum, but to have the acceleration increaſe a day or two after ſhe has paſſed the change at *m*, as 60, 65, 67? after which (going farther and farther from the earth every day till ſhe arrives at the full), ſhe has her motion retarded.

But when the moon changes in apogee, as fig. 3, Plate XLVI. her motion is pretty equally accelerated for eight days before the change, or from *s* to *m*; for increaſing her diſtance from the earth gradually, and that diminiſhing attraction having to contend with the ſolar ſtream at *s*, a balance takes place, ſo that her motion is equal for two days, viz. 44, 44. After which the ſolar ſtream acts every day more and more parallel with the lines in which ſhe gravitates towards the earth, ſuch as 48, 3, and 51, 1, &c. ſo as to render the ſtream of little retarding power: here the ſun's attractive power becomes the greater agent, and cauſes the acceleration denoted by the figures 45, 46, 48, 51, &c. But now that ſhe is arrived at the change ſo diſtant from the earth, ſhe would ſeem to be held between the contending attractions of the ſun and the earth, and here ſhe would ſtop (or find a place where the two attractions balanced each other) if it was not for her vis inertia, or that tendency which all bodies have to continue in the motion they had acquired; this power carries her, by the point of her change in apogee, and hence ſhe begins to be retarded as ſoon as ſhe has paſſed it, according to the numbers 47, 45, 43, &c. But drawing nearer to the earth about her firſt quarter, and of courſe becoming more and more influenced by its attraction; being alſo near the place where the ſun's repulſion begins to overpower his attraction (reſpecting the earth and moon), and expoſed perpendicularly to the impulſe of that ſtream; ſhe begins again to be accelerated, as may be ſeen by the numbers 41, 44, 47, &c.

But when the line of apſides is not in a line with the ſun, moon, and earth, as in the above examples, but the apogee is about the quarters of the moon's path, the attractions and repulſions, the influences and diſturbances, become ſo complex, that nothing but a long ſeries of obſervations can ſolve the great arcana of the moon's *real* motion. Much has been done, and a good deal remains yet to be done; but at preſent it is ſo far known, that the longitude at ſea is better found by the moon's motion than by any other method yet found out.

During the moon's revolution, ſhe always keeps the ſame ſide towards the earth; or rather, perhaps, towards the other focus of her orbit, as *a*, fig. 2, Plate XLIII.; for the meridian *c d* has a conſtant tendency towards the upper focus of the lunar orbit, by which ſhe acquires a longitudinal libration. In her ſyzigies, or conjunctions, at *p* and *z*, the meridian *c d* is in a line with the earth and the focus *a*, and her full face is ſeen; but as ſhe approaches *n*, a little portion of her face on the right diſappears, and a new part appears upon the left, as *o u*; which is again loſt as ſhe approaches *z*. From *z* to *q*, a new portion on her right appears, and an equal quantity diſappears on her left. Theſe are called her *librations in longitude.*

But as her orbit inclines five degrees and three quarters from the plane of the ecliptic *r s*, ſhe will be at *p* ſo much above the level of the earth's path, the ecliptic, that one may look farther under her than at *q*; and when ſhe is in her perigee at *z*, ſhe will be ſo much below the level of the ecliptic, that one may look over her: theſe additions to her uſual face are called her *librations in latitude*, and they reach about ſeven degrees farther than her medium face, towards her other ſide, which we never ſee. A lunar globe has been lately publiſhed by Mr. Ruſſell, that not only ſhews the librations in the moſt perfect manner, but is a complete tranſcript of the mountains, pits, and ſhades on her diſk.

When the moon riſes at the full, in the eaſt, ſhe looks much larger than when ſhe culminates, or comes to the meridian, and is, therefore, called the horizontal moon. This ſeems ſtrange, when we reflect that the moon is conſiderably nearer to us when at the meridian than when in the horizon. Suppoſe a ſpectator at *a*, fig. 4, Plate XLIII. ſees her in the horizon at B, he will ſee her under an angle *c a b*; becauſe the ray from her upper limb *d o* will be ſo refracted by the earth's atmoſphere at *o*, as to be bent into the direction *o a*; and as we ſee every thing along that line in which the rays come to us laſt, we ſee the upper limb of the moon *d* along the line *a c*, and, of courſe, greatly magnified. But when ſhe arrives more in the zenith, or at the meridian A, the rays are not ſo much refracted (ſee Optics) as when they fall more obliquely on the atmoſphere; therefore ſhe appears near her natural ſize. The moiſture and vapours generally over an iſland contribute to this deception. Children believe every thing larger than it is, when looked at through a fog; and only from experience learn to judge right: our want of experience in looking at the heavenly bodies makes us children, till by uſing micrometers, we learn to ſee the moon the ſame ſize in the horizon as at the meridian.

During our winter, the ſun being in the ſouthern part of the ecliptic, the full moons happen in the northern hemiſphere; and (during what we call the light of the moon) ſhine upon the inhabitants within the arctic circle every ſecond fortnight without ſetting, as may be ſeen upon any common globe; ſo that, though they are deprived of the ſight of the ſun, they have ſo much twilight and moon-light, that their ſituation is not ſo forlorn as might be imagined.

Another of what may be called the minor phænomena of the moon, is the harveſt moon. She aſtoniſhes the ignorant by riſing ſix or eight evenings near the ſame time in harveſt, when ſhe is about an hour later in her riſing every day at other times. That ſhe ſhould be near an hour later in riſing every ſecond day, may be made evident by fig. 24, where we will ſay the ſun and moon are together on the meridian at twelve o'clock. Let the line *a c* repreſent a part of the earth's ſurface, and *d* the meridian of any place. Now in the time this meridian makes a revolution, and comes to 12 again, the moon will have travelled from 0 to 1, thirteen degrees (her mean motion) eaſtward, ſo that the meridian *d* will have nearly an hour to turn before it overtakes her. While the meridian makes another revolution, and comes again to 12, the moon has travelled from 1 to 2, and the earth has to turn almoſt two hours before ſhe is overtaken; for the earth turning fifteen degrees every hour, comes near the thirteen degrees which the moon travels every day; ſo that it is evident ſhe muſt riſe and ſet near an hour later every day, and, conſequently, the tides (obeying her motions) will obſerve the ſame intervals every day. But about the autumnal equinox ſhe riſes ſeveral days nearly about the ſame hour. This ariſes from the near approach to a parallel of the firſt part of her road through Piſces and Aries, with the horizon of any high northern latitude. Let *a b* repreſent the horizon, fig. 5, Plate XLIV. and *c d* the moon's orbit as it lies to the horizon when ſhe paſſes through Piſces and Aries; and the ſmall circles, the diſtance ſhe travels every twenty-four hours. When that part of her orbit *c d* riſes out of the horizon *a b*, in the direction *g f*, it muſt neceſſarily riſe in a ſhort ſpace; therefore the ſeven days ſhe is in going from *c* to *d*, ſhe will be but a few minutes later in her riſing every day than the preceding. But at the oppoſite time of the year, viz. in ſpring, her orbit lies a good deal in the direction *g f* to the horizon: then two of the round ſpots, that denote her daily travel, will croſs the horizon in leſs time than the whole ſeven in the former ſituation. This may be made ſtill more plain on a celeſtial globe: for if three patches are placed at thirteen degrees diſtance from each other, on the ecliptic, on each ſide of Aries, and the globe be rectified for London, or any higher latitude, they will be found to riſe out of the horizon almoſt all at once; but if the ſame number be placedat the ſame diſtance about Libra, they will take up ſeveral hours. In this account we have treated the ecliptic as if it was the moon's path; for ſhe deviating from it but five degrees and three quarters, it would make little difference. It may alſo be ſeen that we have twelve harveſt moons in the year; for the moon paſſes through Piſces and Aries twelve times in the year; but at no time ſo convenient to be ſeen as at ſix o'clock in an harveſt evening.

But of all the circumſtances belonging to our moon, there is none in which we are ſo much intereſted as in that wonderful influence we find ſhe has upon the waters of our ſeas, and the air of our atmoſphere: for that ſhe affects both, there can be little doubt, when the tides in each element keep ſuch exact time with her motions. It may be thought, indeed, that we, who are deſtined to grovel at the bottom of our element, can know no more of what paſſes on, or near its ſurface, than thoſe fiſh, which cannot riſe from the bottom, can know of the tides on the ſurface of the ſea. But we know that the barometer is more unſteady at the full and change of the moon than at other times; and that the ſun and moon acting more in a line at the equinoxes than at other times, agitate the air and ſea peculiarly at thoſe periods: it is alſo ſaid, that the full and change affect the nerves of the inſane: all which indicate ſpring tides in the air, as well as the ſea.

When the mind of man became ſufficiently enlightened, he would naturally enquire into the various appearances of nature: the tides would undoubtedly excite his curioſity: he would obſerve that the waters roſe higher at certain times than at others, and that ſuch riſing happened at uniform periods of the moon's motion; he, therefore, could not doubt but ſhe was the cauſe.

That the moon has an influence upon our earth, is certain from the nutation ſhe cauſes in its axis. Suppoſe her in her greateſt declination, and in perigee, fig. 3, Plate XLIV. at *a*. It is evident ſhe muſt have a ſtronger tendency to draw the earth's equatorial protuberance *d c* out of its inclination to the ecliptic, than when ſhe acts upon it more in a line, as *c b*; and thereby to lift the axis out of its natural direction, i. e. into that of *z y*. This nutation was aſcertained by Bradley to alter the direction of the earth's poles

18″ in eighteen years and ſeven months, the great year of the moon.

Was our globe one uniform body of water, or any other fluid, by turning on its axis it would ſoon aſſume an oblate figure. But was it diſturbed by either the attraction or repulſion of another diſtant body, it would not retain that figure, but aſſume one in a ratio compounded of both. Hence if that diſturbance was uniform and continuous, an effect conſtant as the return of the ſeaſons would take place, and intimate that ſomething of that kind muſt be the cauſe of the tides.—The coincidence of the moon's motions with the return and ſucceſſion of the tides, evidently prove the moon to be the cauſe, and that by means of her attraction: for wherever ſhe is ſuſpended over the ocean, ſhe will diſturb its natural gravity at that place; and by diminiſhing its tendency towards the earth's centre, the preſſure of the water which ſurrounds the part ſo diſturbed, will force up that part into an heap or protuberance. This elevation or ſwelling will follow the moon acroſs the Atlantic and Pacific oceans from eaſt to weſt, becauſe the earth turns under the moon from weſt to eaſt. Fig. 2, Plate XLV. will render this doctrine more familiar, where this protuberance is ſhewn both in plan and elevation: *z* in both is the ſwelling (being lighter than the ſurrounding water); *c* and *d* is the ſurrounding water, which being poſſeſſed of more of its natural gravity than the protuberance *z*, and leſs influenced by the moon's attraction, neceſſarily will ſqueeze *z* above its natural elevation.

This influence being aſcertained, its effects upon a flexible fluid may eaſily be conceived. Suppoſe the moon (ſoon after her change) hangs over the ſéa, as fig. 2, Plate XLV.; that by her attraction in the line *a b*, ſhe diminiſhes the gravity, or tendency which the ſea has towards the earth's centre, and cauſes it to ſwell into the protuberance *c z d*: this protuberance cannot be ſtationary; as both the earth and moon are in continual motion; for the earth turning on its axis from weſt to eaſt, under the moon, the protuberance will follow her from eaſt to weſt (like a prodigious wave) over the great Atlantic and Pacific oceans, as before obſerved, and being thrown on the ſhores, will cauſe *flood-tide*, as it is called. It might appear hence, that the waters would be dragged from the European and African coaſts, to the American; and by reverberating back again to them, cauſe a greater length of time between high-water and the moon paſſing the meridian. Certainly the moon paſſes the meridian before it is high-water any-where; for water cannot be put in motion at once: nor can the tides get over ſand-banks, and up creeks and rivers, until ſeveral hours after the moon has paſſed the meridian. Hence, it is not high-water at London until three hours after ſhe has croſſed the meridian. But as the moon hangs principally over the torrid zone, the protuberance under her muſt occaſion a vacancy towards the north and ſouthern zones; and hence the waters ruſh from the north and ſouth towards the torrid zone, in both the Atlantic and Pacific oceans. This protuberance, however, cannot be perceived by a ſhip in ſailing in thoſe vaſt oceans; it is too extenſive; it is only on the ſhores, and in creeks and harbours, that it is viſible. When the ſun and moon are in conjunction and oppoſition, the tides riſe to a more than ordinary height, and they are called ſpring-tides. For the ſun has an influence upon the ſea, as well as the moon; but inconſiderable, from his immenſe diſtance: for as the power of attraction diminiſhes as the ſquares of the diſtances increaſe, the ſun's influence is conſidered only as three, while that of the moon is as ten. At the change of the moon, theſe two powers are drawing the ſame way, and, of courſe, thirteen may be ſaid to be attracting the waters; and produce a ſpring-tide.

Let us now enquire how this travelling tumor viſits the ports and ſhores of the world; and why places (ſeemingly in the ſame circumſtances) ſhould differ ſo widely in their time of high and low water. In the firſt place, it muſt be obſerved, that the moon's influence paſſes the meridian antecedent to her centre; therefore that the tide will *begin* to riſe before ſhe arrives at the place; and alſo begin to ſubſide before her influence has left it: therefore, that as ſoon as the natural attraction of the earth begins to overcome the declining influence of the moon, the protuberance will ſubſide, and return to its natural level. But let us again ſuppoſe a globe entirely covered with water, fig. 2, Plate XLI.; it is evident the moon's greateſt influence would be at *a*, where the water would be higheſt; and that it would become leſs and leſs towards *b* and *c*, and, of courſe, low-water at *d* and *e*. Now, let us ſuppoſe the moon at change, fig. 5, Plate XLV. where the ſun is drawing in the ſame line; and the power of thirteen is operating upon the waters of the ſea; in this caſe, the water will riſe to a more than ordinary height, and be a ſpring-tide, agreeable to experience. But when the moon comes to her firſt quarter at *d*, her influence will be in the direction *d c*, while the ſun's will remain in the direction S *c*: the two powers will in a degree counteract the influence of each other; for the power of ten will act in the direction *c d*, while the power of three only will act in the line *c* S; and hence, at the quarters, neap-tides take place. When the moon comes to the full at *z*, ſpring-tides again take place. How is this?—Are they not now better ſituated to counteract each other than at the quarters? Here we muſt premiſe (what every one knows), that we have two tides in little more than twenty-four hours; i. e. if it be high-water with me at twelve to day, ſituated at *n*, it will certainly be high-water with me ſoon after twelve at night, when I ſhould be at the protuberance *m*: for wherever it is high-water, it is ſo, at the ſame time, to the antipodes of that place. That the ſun and moon's united influence ſhould be leſs at *m* than at *n*, there can be little doubt: but ſtill the place *m* tends to the earth's centre *c*, as much as any other part of the globe, and is rather increaſed than diminiſhed by the two powers which are drawing in the ſame direction. How, therefore, the tide *m* ſhould riſe for want of attraction, or from being left behind, at that place, I cannot conceive, though it is agreeable to the Newtonian hypotheſis.

A ſpectator at the ſun, looking towards the earth and moon, would ſee them paſs from his right towards his left hand, as in the fig. 3, Plate XLV. from A to B, which we will make to repreſent one lunation: the proportions being in the drawing pretty near what they are in nature; i. e. if the ſun be ſuppoſed in the centre of the circle of which A B is an arch, then is *a o* the proportional diſtance of the earth and moon when ſhe is at the change; the diſtances 1, 2, 3, &c. the diſtances the earth travels in one day; and *a b c*, &c. the diſtance the moon travels in one day. Then may it be obſerved how a ſpectator at the ſun would ſee the moon fall every day behind the earth till ſhe came to her firſt quarter at *c*; how ſhe approached to, and paſſed, the earth at the full; how ſhe went before him from the full to the third quarter; and then how the earth approached and overtook her at the change. For it is plain, when the earth is at 3, and the moon at *d*, ſhe would be ſeen behind the earth; and when ſhe was at *v*, and the earth at 20, ſhe would be ſeen before the earth, &c. It may alſo be ſeen by this proportional drawing, that her track through the heavens is always concave to the ſun, as well as that of the earth; that in every revolution ſhe moves in one part faſter, and in another ſlower than the earth; and that ſhe goes from change to change in twenty-nine days and a half. But the drawing is made as if the earth moved round the ſun in a circle; but its orbit is an ellipſe; and there is much reaſon to believe, that it is not the earth that deſcribes that ellipſe, but the centre of gravity, between the earth and the moon, that deſcribes it; for the earth and moon may be conſidered as but one body in reſpect to the ſun, and the impulſe by which he puts them both in motion. For, as the earth and moon mutually attract each other in proportion to their quantity of matter; and as the earth's quantity is calculated to be forty times that of the moon, if her diſtance, 240,000 miles, be divided by 40, it will give 6000 miles as the medium diſtance of the centre of gravity from the earth's centre. This agitation deviates but little from the track of the earth: and an idea of it may be formed from fig. 4, Plate XLV. where A B repreſents a part of the earth's orbit; *a* the earth, *c* the moon, and *d* the centre of gravity between them: now, while the earth travels from *a* to *g*, the moon travels from *c* to *v*, and comes to her firſt quarter; while the earth travels from *g* to *h*, the moon goes from *v* to *n*, and is at the full, oppoſite the ſun; as the earth goes from *h* to *i*, the moon goes from *n* to *o*, and is then at her third quarter; and while the earth travels from *i* to *k*, the moon travels from *o* to *p*, and comes again to the change, &c. From this drawing, it might appear that the moon travelled much farther and faſter in her ſecond and third quarters than in her firſt and laſt; whereas, we find that ſhe performs theſe parts of her orbit pretty nearly in the ſame time, and apparently with the ſame ſpeed. In regard to ſpace, ſhe moves as in the drawing; but in relation to the earth, ſhe moves as far in her firſt as in her ſecond quarter, &c. allowing for the ſituation of her ſyzigies.

The parts of the earth that are, in this period, fartheſt from the moon, will have a ſwifter motion round the centre of gravity than the other parts; or rather, the ſide *c*, fig. 6, Plate XLV. will deſcribe the large circle *m n*, while the ſide *a* will only deſcribe the ſmall circle *p q*, round the centre of gravity *o*. Now, as every thing in motion always endeavours to go forward in a ſtraight line, the water *c*, having a tendency to fly off in the line *c r*, will in a degree overcome the power of gravity, and ſwell into a heap or prŏtuberance, as repreſented in the figure, and occaſion a tide oppoſite to that cauſed by the attraction of the moon; and account for the two tides which take place every twenty-four hours and fifty-two minutes. This centrifugal tendency may be well illuſtrated by ſwinging a tumbler full of water vertically round, when the water will not be ſhed though its mouth be downward.

At the change of the moon, the ſun's influence is added to that of the moon, and the centre of gravity will, therefore, be removed farther from the earth than *a o*, and, of courſe, increaſe the centrifugal tendency of the tide *c*: hence, both the attracted and the centrifugal tide are ſpring-tides, at that time. But ſpring-tides take place at the full as well as the change of the moon. Now it has been premiſed, that if we had no moon, the ſun would agitate the ocean in a ſmall degree, and make two tides every twenty-four hours, though upon a ſmall ſcale; his influence (from his diſtance) being but as 3, while that of the moon is 10. The moon's centrifugal tide, along the arch *c d*, fig. 7, Plate XLV. being increaſed by the ſun's attraction, will make the protuberance a ſpring-tide; and the ſun's centrifugal tide, along the curve *b i*, will be reinforced by the moon's attraction, and make the protuberance *b* a ſpring-tide: ſo ſpring-tides take place at the full, as well as change of the moon.

When the earth's axis inclines towards the ſun, as in ſummer, and the moon is new, the day tides, in the north, will be greateſt, and night tides loweſt: at the full, the reverſe. Fig. 8, Plate XLV. will render this plain: *a* is the tropic of cancer, over which the moon is vertical; the day-tide, therefore, at *a*, will be higheſt: but the tropic at *b*, in the night-tide, will evidently dip but a little into the ſwell, and, therefore, be lower: at the arctic circle, at *c*, it is alſo evident there will be but one tide in the twenty-four hours.

When the moon is vertical to the equator, about her change, the ſun's influence and hers will coincide; and their joint influence raiſe the tides to a more than ordinary height: this happens about the time when the ſun croſſes the equator, in March and September, when equinoctial tides and ſtorms are proverbial; ſee fig. 8, Plate XLV. But as the ſun is nearer the earth in winter than in ſummer, and, of courſe, nearer in February and October than in March and September, theſe equinoctial tides generally happen a little after the autumnal equinox, and a little before the vernal.

The time of the tides does not always anſwer to the ſame diſtance of the moon from any meridian: for the ſun's attraction, at her change, retards her motion a little, particularly when both are in a line with the earth. This is one of the cauſes that make lunar calculations ſo difficult. Neither do they happen alike to places on the ſame meridian; for capes, ſands, ſhoals, creeks, &c. retard their motion, and hence they happen at every hour to thoſe places from the moon's departure from a meridian until her return to it again. Tides alſo are not ſo much perceived in the open ſea, as in bays and rivers; which having wide mouths, and growing narrower, the *vis inertiæ* of the water in motion is ſuch as to make it riſe, like a huge wave, many feet above the level of the ſea whence it came.

The time of high water at any place, being known, at the change and full of the moon, the time of high water at all other times may be eaſily reckoned, as that is about 52 minutes at a medium later every day. For as the earth turns on its axis 15° every hour, ſo 13° (the moon's daily motion), wanting but two degrees of the fifteen, it is generally ſaid that the tides are an hour later every day, when in reality it is but about 52 minutes, anſwering to the 13°. Hence, if it be high water at twelve on *Monday*, it will be high water again at 52^{m} paſt twelve on *Tueſday*; and on *Wedneſday*, at 44^{m} paſt one, &c.

Here follows a few places, with the time, by their clocks, when it is high water at the change and full.

	H	M		H	M
Amſterdam - - -	3	0	Cadiz - - - -	4	30
Antwerp - - - -	6	0	Cape Clear - - -	4	30
Archangel - - -	6	0	Cowes - - - -	10	30
Baltimore - - - -	5	15	Dieppe - - - -	10	30
Bayonne - - - -	3	30	Dover - - - -	11	30
Breſt - - - -	3	33½	Dunkirk - - - -	11	45
Boulogne - - - -	11	0	Dublin - - - -	9	15
Briſtol - - - -	6	45	Mouth Seine - - -	9	0
Brighthelmſton - - -	10	45	Mouth of the Severne -	6	0
Beachy-head - - -	0	0	Mouth of the Thames -	12	0
Bourdeaux - - -	3	0	Edinburgh - - -	4	30
Cape of Good Hope - -	2	30	Ediſtone - - - -	5	30
Cherbourg - - -	7	30	Falmouth - - - -	5	30
Calais - - - - -	11	30	Gibraltar - - - -	0	0
Cork - - - -	6	30	Havre de Grace - - -	9	0

	H.	M.		H.	M.
St. Helena	2	15	North Cape	3	0
Haſtings	11	0	Oſtend	11	45
Iſle of Wight	9	0	Plymouth	6	0
Kinſale	5	15	Portland Iſle	8	0
Lizard	7	30	Portſmouth	11	15
Liſbon	2	15	Quebec	7	30
London	3	0	Rotterdam	3	0
Milford Haven	6	0	Senegal	10	30
Madeira	12	14	Weymouth	9	0
St. Mary's Scilly	3	45	Waterford	10	30
Newcaſtle	3	0	Yarmouth	1	30
Nantes	3	0	New York	3	0

To attempt a reaſon why the tides take place ſo different in time, to places that are on the ſame meridian, we muſt enquire into the geographical locality of their ſituation. *Amſterdam* has high water three hours after the ſun and moon at their conjunction have paſſed its meridian; *Antwerp*, not half a degree weſt of the meridian of Amſterdam, has not high water till ſix: the map points out the reaſon. Tides (obeying the motions of the moon) flow from the north along the coaſt of Holland, ſouthward; at the Texel they are obſtructed by ſand banks, and crooked paſſages into the Zuyder Zee, ſo that before the wave riſes to its greateſt height at Amſterdam, it is three hours after the ſun and moon together have paſſed its meridian.

But at Antwerp, the crooked obſtructions in its paſſage up the Scheld requires more time; hence it is ſix hours after the ſun and moon have paſſed the meridian before it is high water at Antwerp. So it is at *Archangel*, by the intricate winding ſhores of the White Sea. *Baltimore*, in North America, has high water at a quarter paſt five, by their clocks, i. e. when the ſun and moon at their conjunction have paſſed near eighty degrees over the meridian of Baltimore; ſo that the influence has got half over the Pacific Ocean before the effect has reached Baltimore. When we conſider the width of the Atlantic Ocean, and the inertia of water, it ſeems very natural that the wave ſhould be left far behind the moon. Bayonne, in the bay of Biſcay, receives its high water by a returning tide from the Atlantic; for when the ſun and moon have nearly croſſed the Atlantic, the wave which followed them will return to Bayonne, three hours and a half after they have croſſed its meridian. *Breſt*, though nearer to the returning wave than Bayonne, has an indented entrance into its harbour, and therefore, by its obſtruction, has its high water nearly about the time of Bayonne: for though a wave may follow the moon quite acroſs the Atlantic, as well as the Pacific Oceans, it cannot follow ſo faſt, i. e. at the rate of fifteen degrees per hour; therefore, being left behind, that portion of it that has loſt the moon's influence will return, and cauſe high water all along the weſtern ſhores of Europe and Africa, conſiderably after the moon has paſſed their meridian. Hence we ſee in the table, that high water takes place nearly about the ſame time at Scilly, Liſbon, Cadiz, St. Helena, Cape of Good Hope, &c.

The tide thus returning from the Atlantic, makes its way up the Engliſh, or St. George's Channel, progreſſively: at Falmouth and the Eddiſtone (at new moon) it is high at half paſt five; Plymouth, at ſix; Cherburg, at half paſt ſeven; Portland, at eight; Weymouth, at nine; Havre de Grace, at nine; Iſle of Wight, at nine; Dieppe and Brighthelmſtone, half paſt ten; and at Dover and Dunkirk, at half paſt eleven.

Here the tide up the Channel is met by one from the German Ocean; their meeting is contentious, and cauſes what the ſeamen call a ripple in the ſea; but two ſuch bodies of water meeting, cannot eaſily be ſtopt, but will, agreeable to the laws of motion, riſe each above its natural level, and cauſe that ſwelling in the Strait of Dover, and of courſe in the mouth of the Thames, ſo as to occaſion its flood tide to be much more rapid than its ebb, and to be performed in two hours leſs time.

It may be aſked, why the tides riſe ſo little among the iſlands of the Weſt-Indies (ſeldom more than twelve or fourteen inches), when theſe iſlands are ſo much more under the influence of the moon, than countries where the tides riſe thirty or forty feet? To this it muſt be anſwered, that as the Atlantic turns under the moon, from weſt to eaſt, her influence on its water muſt be from eaſt to weſt; this tide, like a prodigious wave, is ſtopt by America, and reverberates back as the moon paſſes over the Pacific Ocean. But in the ſame direction that the moon drags the waters of the Atlantic, the trade winds conſtantly blow; and ſo great is the power of wind, that tides every-where are made greater or leſs according as the wind is with them, or againſt them. Now the Gulf of Mexico is a cavity between North and South America, into which the winds and tides are perpetually pouring in water; ſo that the firſt tide that ever flowed into it, may be ſaid to be kept up in it by this unremitting influx; and, of courſe, the tides cannot riſe and fall as in places leſs in the way of theſe two cauſes. But water raiſed above the general level always endeavours to fall back to that level; the trade winds, in ſome meaſure, prevent this, by blowing perpetually from the eaſtward. As water, ſo accumulated, cannot return in the teeth of the trade winds, it wheels round the weſt end of Cuba, and meeting with the Bahama Iſles, is turned northward along the coaſt of America; forming that moſt remarkable ſtream, the ſtrong current of the Gulph of Florida. To ſhew that this accumulation does take place in the Gulph of Mexico, a ſurvey was made acroſs the Iſthmus of Darien, when the water on the Atlantic ſide was found to be fourteen feet higher than the water on the Pacific ſide. It alſo is not improbable, from the ſhape and ſituation of the Weſt-India iſlands, that they are the remains of a continent; the lower lands being waſhed away by the above influxes, and their places now occupied by the Carribean ſea.

On the outſide of Great Britain and Ireland, the tides run naturally from the north *towards* the moon; but between the iſlands they run unnaturally from the ſouth towards the north, *from* the moon. This is occaſioned by the near approach of the north ends of the two iſlands, and the obſtruction given the tides in flowing through the Hebrides; hence, as the ſouthern ſeparation of the two iſlands is much wider, it is a more convenient entrance for the tides, and the Iriſh Sea experiences a tide flowing from the ſouth.

At the Naze of Norway there are no tides; for the efflux of water from the mouth of the Baltic meets the tide of the North Sea at right angles, and confounds its riſe and fall.

There is a perpetual influx of water through the Straits of Gibraltar into the Mediterranean: but this is not a tide; the moon has nothing to do with it. The ſandy ſoil and deſerts on the ſouth of this great ſea, receive immenſe heat from the ſun, and impart it to the winds that paſs over them; and as heated menſtruums will diſſolve more than cold ones, a ſouth wind cauſes ſo great an evaporation on the ſurface of this ſea, as to ſink its level below that of the Atlantic: the ocean, therefore, pours perpetually in at the ſtraits to reſtore that level. This evaporation is often ſo great, that the ſails of ſhips are kept wet by the half-diſſolved dews juſt above the ſurface; and theſe winds (called Sirocco), when they reach Greece and Italy, are ſo hot, and full of vapour, that they unnerve and diſtreſs every creature that cannot eſcape out of their way.

There are many apparent exceptions to this doctrine reſpecting the tides: the Mediterranean has but ſmall tides; the Baltic none. In the Euxine and Caſpian, they can ſcarcely be perceived: the moon's duration on the meridian of theſe ſmaller bodies of water, is too ſhort to put them in motion. The *inertiæ* of water is not eaſily overcome: for if the moon's influence was ſuſpended for a while, and the waters ſubſided into their beds, when the moon reſumed her influence, it would be ſome time before even the oceans themſelves could be brought into that regular vibration they have at preſent. Capes, headlands, ſhoals, rocks, the inequalities at the bottom of the ſea, &c. all contribute to the irregularity; but theſe allowed for, the whole is reconcileable to the above theory.

NEWTONIAN DOCTRINE, RESPECTING THE LAWS OF PLANETARY MOTION.

1ſt law. *Every body, or portion of matter, would continue in its preſent ſtate of reſt or motion, if not diſturbed by ſome external cauſe.* This is called the *vis inertiæ* of matter, or that tendency which all matter has to lie ſtill when not moved by external impulſe, and to go on when put into motion. If a body be laid in any place, there we are ſure to find it, if nothing removes it: and if I throw a ſtone, it would go for ever in the ſame line, if the reſiſtance of the air, the power of gravity, or ſome other cauſe, did not ſtop it.

2d law. *All motion, or change in motion, is proportional to the force* *that is the cauſe thereof:* i. e. if a certain force moves a body with certain velocity, a double force will double that velocity, &c.; and if a body be actuated by two contrary forces, it will obey neither, but proceed in a direction compounded of both. Thus, if I throw a ſtone in the direction *a b*, fig. 1, Plate XLVII. while the power of gravity pulls it in the direction *a c*, it will neither ſolely obey the power of gravity, nor my impulſe, but go in the diagonal *a d*, compounded of both.

3d law. *Re-action is always equal and contrary to action.* Thus, if a man in a boat pulls another boat of equal weight by a rope, they will approach each other with equal velocity, and meet in the middle of the way. So in rowing, ſwimming, and flying; the oar may be ſaid to puſh the water one way, the water puſhes the boat the contrary way. Thus a man ſwimming puſhes the water one way, and the water drives him the contrary way. Birds beat the air backward with their wings; the air drives them forward. So it may be ſaid, that when a hammer ſtrikes an anvil, the anvil returns the ſtroke. If I ſtrike a ſtone with my hand, the effect is the ſame as if the ſtone ſtruck my hand, &c.

Though theſe ſimple laws appear ſelf-evident, they are equally explanatory of celeſtial phænomena as of the appearances on the earth. For if we find that the moon and planets fall from a tangent projected to their orbits, as a bullet does, ſhot from a precipice; this is ſtrong proof that they are actuated by the ſame laws (ſee fig. 2, Plate IX. Mechanics), and that their orbits are occaſioned by a compounded force, the projectile force tending to a ſtraight line, while the power of gravity bends that line into an ellipſe. But why into an ellipſe?—In the firſt place, let us ſuppoſe a round board, *a*, fig. 2, Plate XLVII. put into a ſwift circular and horizontal motion, with a ball *c* upon it, and pulled towards the centre *d*, by a ſtring and a weight hanging under the board: this weight may repreſent the gravity which any planet has towards the central ſun. When the ball *c* partakes of the motion of the board, it will fly farther and farther from the centre *d*, till its tendency to fly off in a ſtraight line ſhall be balanced by the weight beneath the board: its motion then will be perfectly circular; its centrifugal tendency being juſt a balance for the centripetal. Here then is a law by which one body may revolve round another without coming nearer, or receding farther from its attracting centre. But early in the progreſs of aſtronomy, it was found, that the moon and planets moved ſwifter in ſome parts of their orbits than in others; and that their parallax was accordingly greater in thoſe ſituations in which they move faſteſt: from theſe obſervations, there was proof of their orbits being elliptical; and that there had been no particular adjuſtment in balancing the centrifugal to the centripetal forces, at their firſt creation: and the celebrated Kepler had diſcovered, that a two-fold power of projectile or centrifugal force, would balance a four-fold power of gravity at all diſtances from the attracting centre. Let us familiarize this by fig. 5, Plate XLVII. and ſuppoſe a planet, *a*, projected in the line *a d*, with a power inferior to the power of gravity *a* S: then would the centripetal power ſo far prevail over the centrifugal, as to bring the planet down to *c*: but what ſhould prevent its nearer and nearer approach, until, in the ſpiral *c e*, it fell to the ſun? Here this wonderful law becomes conſpicuous. At *c*, the planet being twice as near to the ſun as at *a*, it has four times the gravity at *c* as at *a* (becauſe the power of gravity diminiſhes as the ſquares of the diſtance increaſe); but in its deſcent from *a* to *c*, its velocity increaſes by coming nearer and nearer to the ſun, ſo that at *c* we will ſuppoſe it moves twice as faſt as it did at *a*. Now all motion having a tendency to become rectilinear (i. e. if motion be given to a body in ever ſo crooked or oblique a way, it will always endeavour to fly off in a ſtraight line), the velocity which the planet has acquired at *c*, is not in favour of the ſpiral line *c e*, but in that of the tangent *c g*. Now if the four-fold tendency *c* S can be balanced by the two-fold projectile force *c g*, we ſee how the planet can relieve itſelf from the ſtrong influence of the ſun at its perihelion, and aſcend by *k* to its aphelion at *a*. This is proved by actual obſervation of the planetary motions; and eaſily made evident by the whirling-table.

Let the pulley *a*, fig. 5, Plate XLVII. be ſuppoſed to be turned by a large wheel, and along with it the weights *b*, and the ball *c*, ſliding on the wire *w*. The four weights are over the centre of motion, and to be lifted by a ſtring going over the pulley *h*, and under the pulley *i*, and faſtened to the heavy ball *c*. Fig. 6, Plate XLVII. is actuated by the ſame large wheel; but the pulley *s* being twice the diameter of the pulley *a*, this part of the machine will but move half as faſt as the other. Now as the balls *c* and *o* are of the ſame weight, and at the ſame diſtance from the centres of motion, their momenta muſt be the ſame, if they had equal motions. But it has been affirmed, that a two-fold motion, or power of projectile force, will balance a four-fold tendency to the centre. If ſo, the double ſwiftneſs of the pulley *a*, ſhould make the ball *c* lift the four equal weights *b*, at the ſame inſtant the projectile tendency of the ball *o* ſhould lift the ſingle weight *k*, and ſhew that a two-fold velocity will balance a four-fold power of gravity. This is exactly ſo; and if this proportion was deſtroyed, by adding or withdrawing a weight, the experiment would not ſucceed.

By this do we diſcover another rule, viz. that all the planets, as well as their ſatellites, *deſcribe equal areas in equal times.* Suppoſe S the ſun, in fig. 4, Plate XLVII. and *a* the planet at its perigee; the ſtrong tendency it has to fly off in the direction *a b*, brings it in a given time to *c*; in the ſame time it moves from *c* to *d*; and in the ſame time, from *d* to *e*, &c. But all the triangular ſpaces, 1, 2, 3, 4, &c. are equal to one another, and of equal area; ſo that if the planet carried a ſtring with it, one end of which was faſtened to the centre of the ſun, the ſtring would paſs over equal ſpaces in equal times. Thus do we ſee why our ſummer half-year is eight days longer than our winter half-year, as is plain by the figure; and why, perhaps, there is ſo much more land in our northern hemiſphere than in the ſouthern, being more fit for inhabitants by the medium ſeverities of its ſeaſons; for the earth being neareſt to the ſun in our winter, the rigour of that ſeaſon is meliorated; and being fartheſt from him in our ſummer, that ſeaſon has alſo its heat moderated. In the ſouth, the contrary takes place; that hemiſphere is addreſſed to the ſun in their ſummer (being our winter), when the earth in her orbit is neareſt to the ſun; accordingly it is found that, latitude for latitude, their ſummer is much hotter, and winter much colder than ours. This unequal diſtance is alſo found by meaſuring the ſun's apparent diameter with a micrometer, when it will be found, that the ſun appears $32''$, about $\frac{1}{30}$ of his diameter, larger at midwinter than at midſummer.

The elliptic orbit of the moon is irregular, as her motion is much diſturbed by the attraction of the ſun: this is evident in the winter, when the ſun is neareſt to us; for then ſhe is ſo retarded by him, that her periodical month is longer than in ſummer. By this attraction, alſo, is the acceleration of the place of her nodes brought about;

and the greater and leſs angle her orbit makes with the ecliptic every revolution : from theſe circumſtances, ſhe cannot exactly deſcribe equal areas in equal times.

Diſtances of the Planets.—The ſhape of the orbits of the planets, and laws of their motion in them, being thus aſcertained, we muſt now try to find their diſtances. Though this is a proceſs not quite within the ſphere of popular information, yet, I truſt, it may be made plain even to thoſe who have not made mathematics a ſtudy. Suppoſe the diſtance of the moon were our firſt object, and that we had a ſea horizon, and were ſituated ſo as to have the moon paſs our zenith. Then let A be the earth, fig. 7, Plate XLVII. and *a* the place of the obſerver, who muſt be ſuppoſed to have a quadrant, *b c*, by which he can note the moment the moon comes to the zenith. Now, as the moon apparently paſſes from a meridian to that meridian again in twenty-four hours and forty-eight minutes, ſhe will perform a quarter of that circuit, viz. from *d* to *e*, in a quarter of that time, or in ſix hours and twelve minutes. But the obſerver will find that ſhe will ſet before the ſix hours and twelve minutes are expired, which he muſt note : for when ſhe comes to his ſenſible horizon *a c g*, ſhe ſets to him. Now, as the ſenſible horizon is parallel to the rational horizon *k e*, a diagonal *a e* will make the angle *c z* equal to *n*, its oppoſite angle. To find what the angle *c z* is, ſay, by the rule of three, If ſix hours and forty-eight minutes be required for a quarter of the moon's circuit, or 90°, viz. from *d c* ; how many degrees of the 90 would ſhe paſs through in the time of her going from the zenith to the ſenſible horizon, or from *d* to *g*? This will give the degrees of the arch *dg*, which being taken from 90°, or the quadrant *d e*, will leave the quantity of the arch *g e*, or the angle *c z*. Now, as the angle *n* is equal to *c z*, we are in poſſeſſon of a right-angled triangle, *a k e*, with a ſide and an angle known; for *a k*, the ſemi-diameter of our globe, is 3960 miles: now it is the property of a right-angled triangle to have its ſides proportional to the ſines of its oppoſite angles; therefore, as the angle *n* is to its oppoſite ſide *a k*, ſo is the angle *o* to its oppoſite ſide *k e*, or the mean diſtance of the earth's centre from that of the moon, viz. 240000 miles. This parallax, or angle *n*, is on a medium about 57″. But the refraction which a ſetting ſun or moon's rays ſuffers near the horizon (ſee Optics), makes a conſiderable difference. This method does well enough for finding the diſtance of the moon in, or near, the torrid zone: but the ſun is ſo diſtant, that his parallax or angle *g a* S is too ſmall to be meaſured to any certainty, by an horizontal parallax. Dr. Halley, therefore, recommended the tranſits of Venus, which were to happen in the years 1761 and 1769, as the moſt perfect phænomena for aſcertaining the diſtance of the ſun. But even, as to the moon, on looking in our Nautical Ephemeris, we find the moon's parallax altering in the courſe of one month from 54′ to 61′, the cauſe of which may be ſeen in fig. 8, Plate XLVII. Let E be the earth, and *a* its centre; from that centre (if the earth was tranſparent) we ſhould transfer the moon at *b* to *c* in the ſtarry heavens; when ſhe was at *e*, we ſhould ſee her at *x*; and when ſhe was at *g*, the eye at *a* would transfer her to *z*, &c. Theſe are ſaid to be the *true* places of the moon. Her *apparent* places, are thoſe in the heavens where ſhe is ſeen when viewed from any part of the earth's ſurface. So that a ſpectator at *u* would ſee her at *d*, when ſhe was at *e*; and when ſhe got to *g*, he would ſee her at *p*, &c. &c. So that the angle *e a b* would be her parallax, equal to the angle *x e d*: and hence her parallax is evidently moſt when near the horizon; it is leſs between *p* and *z*; leſs ſtill between *n* and *m*; and none at all at the zenith *s*. So that with the greater or leſs obliquity with which ſhe is ſituated to an obſerver, the parallax is perpetually varying.

By the tranſits of Venus, almoſt the *whole* diameter of the earth formed a parallax, inſtead of the above ſemidiameter, by which a commenſurate angle was procured in this way. Venus moves in her orbit in the direction *z n*, fig. 10, Plate XLVII.; and from the centre of the earth, *c*, would be ſeen to move over the ſun's diſk from *s* to *v*: an obſerver, therefore, at *a*, would ſee the contact at *s*, at the ſame inſtant that one at *b* would ſee the planet at *u*; and one at *d* would ſee it at its egreſs at *v*, along the line *d* V *v*: this would be the caſe were the earth at reſt; but it is turning on its axis, in the direction *a b d*. Now if the planet ſtood ſtill at V, while the earth turned from *a* to *d*, that time would be eaſily turned into the parallactic angle *a* V *d*, and might be treated like that of the moon: but the motion of Venus, as well as that of the earth, was to be taken into this calculation, as well as obſervations made in different latitudes: the reſult of all which was, that the ſun's parallax was found to be but about 8″; but ſmall as it is, 'tis an angle whoſe ſides admit of calculation; and the ſun's diſtance, by this means, was found to be about 96 millions of miles.

The ſun's diſtance being thus found, the diſtance of the planets from him may be found, either by their retrograde motions, or by the celebrated problem of Kepler, viz. that the ſquares of the periodical times of the planets, round the ſun, are in proportion to the cubes of their diſtances from him. As the times, therefore, of the revolutions of the planets are well known, and as we know now the diſtance of the earth from the ſun, how am I to find the diſtance of Mars from the ſun?—By knowing that he is 686 days 23 hours 30 minutes and 36 ſeconds, in going round his orbit. By the rule of three, it will be as the ſquare of the periodic time of the earth's motion round the ſun (i. e. 365 days 6 hours 9 minutes 12 ſeconds) is to the cube of its diſtance (i. e. the cube of 96 millions of miles), ſo is the ſquare of Mar's periodical time (i. e. 686 days 23 hours 30 minutes 36 ſeconds) to the cube of his diſtance from the ſun. The cube root being extracted from that number, repreſents the proportional diſtance of Mars from the ſun.

The way of finding the diſtance of a planet from the ſun, by its retrograde motion, and by knowing the earth's diſtance from the ſun, is thus, fig. 9, Plate XLVII. : Let S be the ſun, *e* the earth, and *m* the planet Mars, whoſe diſtance from the ſun is the object of enquiry; and let *a*, *b*, and *c*, repreſent an arch of the heavens. Now, as the earth moves almoſt twice round the ſun while Mars moves but once, every twenty-ſecond month we paſs by him, and he appears at every time to go backward: for when the earth is at *e*, Mars would be ſeen at *a*; but as the earth paſſes from *e* to *d*, Mars would have appeared to go retrograde from *a* to *c*, though, in reality, he was going the ſame way as the earth, viz. from *m* to *g*. The arch *a c* is found by obſerving the planet in its retrograde ſtate, and that gives the angle *a m c*, which is equal to the angle *c m d*, half of which is the angle S *m c*: hence we come in poſſeſſion of an angle, and its oppoſite ſide of the right-angled triangle S *m c*; for S *c* is the diſtance of the earth from the ſun, and the angle *m* is found as above: ſo, as the angle *m* is to the ſine S *c*, ſo is the angle *c* to the oppoſite ſide S *m*, or the diſtance of Mars from the ſun.

This problem is performed as if Mars ſtood ſtill at *m*, while the earth was moving from *c* to *d*; but, in reality, he is going forward to *g*, and would be ſeen from *d* at *b*. But ſince the quantity of Mars's motion, during the time of his retrogradation, may eaſily be found, it may be known how much the angle *a m c* is diminiſhed, and, conſequently, what that retrograde motion would have been had he ſtood ſtill at *m*.

This method is applicable to all the ſuperior planets; and the diſtance of the inferior planets from the ſun, may be found by a ſimilar proceſs. Let S be the ſun, fig. 1, Plate XLVIII.; *a* the planet Venus, at her greateſt elongation (or that place where ſhe appears the fartheſt diſtant from the ſun); *b*, the earth; and *c d*, a portion of the ſtarry heavens. The triangle *a b* S is a right one; and the angle *b* is eaſily taken with a quadrant: being, therefore, in poſſeſſion of that angle, and the line *b* S (the earth's diſtance from the ſun), the perpendicular (or Venus's diſtance from the ſun) is found by plane trigonometry, as in the laſt problem.

The mean diſtance of each planet from the ſun being thus found, we double that diſtance, and it is the diameter of their orbit; and as the diameter of a circle is to its circumference nearly as 7 is to 22, their orbits and hourly motion may be eaſily calculated, viz.

				millions of miles.
That Mercury	goes round the ſun at the rate of	110680	miles in an hour, at the diſtance from him of	$37\frac{1}{3}$
Venus		80955		$69\frac{1}{2}$
Earth		68856		$146\frac{1}{3}$
Mars		55783		$499\frac{3}{4}$
Jupiter		30193		$916\frac{1}{2}$
Saturn		22298		1832
Georgium Sidus		16411		

This aſtoniſhing diſtance and velocity may be expreſſed in numbers: but neither numbers nor diagrams can implant in the mind any diſtinct idea of thoſe aſtoniſhing diſtances, or motions! (which are yet almoſt as nothing to other diſtances, and other velocity), By applying facts and images to which we have been accuſtomed to aſſiſt the mind, a faint conception may be formed of them. A cannon ball moves at the rate of eight miles in a minute: according to this, it may be computed, that in flying from the ſun it would require the following time to reach

Mercury - - -	$8\frac{3}{4}$ years.
Venus - - -	$16\frac{1}{2}$
Earth - - -	$22\frac{3}{4}$
Mars - - -	$34\frac{3}{4}$
Jupiter - - -	$118\frac{3}{4}$
Saturn - - -	$217\frac{3}{4}$
Georgium planet - -	$435\frac{1}{2}$
The fixed ſtars -	7,600,000

If balls, placed on poles, were made to repreſent the ſun and planets,

Mercury ſhould be -	28 yards from the ſun.
Venus - - -	52
Earth - - -	79
Mars - - -	109
Jupiter - - -	273
Saturn - - -	684
Georgium planet - -	1357

Moon $6\frac{1}{2}$ inches from the earth.

The ſize of theſe balls, to bear a proportion to the above diſtances, ſhould be,

The Sun - - -	2 feet diameter.
Mercury - - -	$\frac{1}{12}$ inch.
Venus - - -	$\frac{1}{7}$
Earth - - -	$\frac{1}{5}$
Mars - - -	$\frac{1}{15}$
Jupiter - - -	$2\frac{3}{4}$
Saturn - - -	$2\frac{1}{10}$
Georgium - - -	1 inch.

Another mode of expreſſing proportional diſtances from the ſun:

4	7	10	15	52	95	120
☿	♀	⊖	♂	♃	♄	♅

The diſtances of the planets being known, their magnitudes are calculated by their apparent diameters, at thoſe diſtances. The ſun, when ſeen from oppoſite ſides of the earth at the ſame moment, appears in the ſame place, becauſe of his great diſtance, and the ſmall comparative ſize of the earth. The moon (though apparently as large as the ſun) appears, to two obſervers, at only a few leagues from one another, in different parts of the heavens, on account of her nearneſs, and great parallax, which is 430 times as great as the ſun's; the diſtances of the heavenly bodies being inverſely as the tangents of their horizontal parallaxes. And we have obſerved that ſpectators, on different parts of the earth, ſaw Venus on different parts of the ſun's diſk, at the ſame moment. From thoſe diſtances, and the angle the planets ſubtend at thoſe diſtances, their magnitudes are calculated with tolerable certainty. Their largeſt apparent diameters, as ſeen from the earth, are, the Sun 32′ 36″, Mercury 12″, Venus 57″, Mars 27″, Jupiter 40″, Saturn 18″, the ring of Saturn 42″, Georgium Sidus 4″. Their real diameters, proportional diſtances, ſidereal revolutions, &c. are expreſſed in the following table:

	Diameters in Engliſh miles.	Proportional diſtance from the ſun.	Sidereal revolution.	Inclination of their orbits.
Sun	893522		d. h. m. s.	
Mercury	3261	38710	87 23 15 14	7° 0′ 0″
Venus	7699	72333	224 16 49 11	3 23 35
Earth	7920	100000	365 6 9 10¼	
Moon	1161		27 7 43 0	
Mars	5312	152369	686 23 30 36	1 51 0
Jupiter	90255	520279	4332 14 27 11	1 18 56
Saturn	80012	954072	10759 1 51 11	2 29 50
Herſchel	34217	1008180	83 years, 157 days and 18 hours.	0 46 20

CHARACTER AND PROPERTIES OF THE PLANETS.

The Sun.

THIS vaſt globe is the firſt of the celeſtial bodies that attracts our notice. It is the fountain of light, heat, and fire; the great illuminator of the world! It is the centre of the planetary ſyſtem, adminiſtering to the various worlds which compoſe it, light, heat, and vegetation. By his attraction and repulſion he retains the planets in their orbits. His magnitude, diſtance, and denſity, have been calculated; and ſo many of his attributes aſcertained, that there remains little doubt of his being, as it were, the ſoul and actuating principle of the ſyſtem; as well as a world ſuſceptible of inhabitants. By ſpots on his face we can ſee that he turns round an his axis in twenty-five days and ſix hours from eaſt to weſt. If the emiſſion of light were the whole of his deſtination, we ſee no reaſon why that might not be performed by a body at reſt, as well as by one in motion. It ſeems conſiſtent with analogy, and the frugality of Nature, in never doing any thing in vain, that this motion is to throw off centrifugal light through the zodiac; and thereby to give annual and diurnal motion to the planets. (See Optics, &c.)

Thoſe ſpots by which we eſtimate the time of the Sun's rotation on his axis, have been thought the ſmoke of volcanos; ſcum floating on an ocean of fluid matter; clouds; nay, the Sun himſelf has been conſidered as a globe of fire. But, by obſerving them with a due magnifying power in teleſcopes, they are found to be hollow, and may be ſeen diſtinctly when they arrive at the edge of the ſun, where a ſmall indentation will appear on that edge, as *a*, fig. 2,

Plate XLVIII.; and from the ſhade that is ſeen round each ſpot, there appears a ſhelving ſlope into each pit. Now this appears as if in common we did not ſee the real ſun, but only its atmoſphere, which, perhaps, may be of fluid fire, ſurrounding his black body like an ocean; and in which there may be commotions that may temporarily lay part of his body bare, and account for the ſpot, its ſurrounding ſhade, and the ſlip that ſeems cut out of the ſun's edge when the ſpot is diſappearing. Or, perhaps, we may ſee the dark nucleus through a thin part of his fluid atmoſphere, as we ſee the wick of a candle through its flame; or the opaque ore through the intenſe flame of a furnace. This makes the Sun more like the reſt of the ſyſtem than any other ſuggeſtion that has yet appeared, and pleads ſtrongly in favour of his being inhabited. Nay, indeed, we may conſider him as the only planet in the ſyſtem, and that our earth and the other worlds are but his ſatellites! Glorious luminary! can we blame ignorance for making thee a god! What a body muſt he be, when the whole orbit of the moon could not contain him! when his attraction and influence reach even beyond the Georgium Sidus! His axis inclines eight degrees from a perpendicular to the plane of the ecliptic, by which his centrifugal light (flying off in the plane of his equator) riſes a little above, and falls a little below, the level of the ecliptic: this light may be ſeen a little before the ſun riſes, about the time of the ſolſtices, and is called the *zodiacal light:* we preſume this ſtream of light to be the cauſe of annual and diurnal motion in all the planets, and of all their irregularities. (See Section 1ſt and 2d, Introductory Lecture.)

Mercury. ☿.

This ſmall planet moves round the ſun ſo near to his body, that it is ſeldom we ſee him; and when we do, it is for ſo ſhort time, and always in the twilight, that we can ſee no ſpots upon his face, and conſequently know nothing of his diurnal motion, or length of his days and nights: but we can ſee that he performs an annual journey round the ſun in eighty-ſeven days twenty-three hours and ſixteen minutes; ſo we ſay, in round numbers, his year conſiſts of eighty-eight of our days. When we do ſee him, he appears like a little half-moon, ſhewing that he borrows his light from the ſun. His annual motion and borrowed light being thus aſcertained, we doubt not of the other qualifications neceſſary to make him a fellow world with the reſt of the ſyſtem; and though his heat is calculated to be ſeven times as great as ours, no doubt his matter and inhabitants are adapted to it.

As the inclination of Mercury's orbit is ſeven degrees oblique to the ecliptic, he can be well obſerved only near our equator, and ſeldom in high latitudes: therefore, though he paſſes ſo ſwiftly round the ſun, it is generally above or below him; but when he paſſes through his node at the time of his conjunction with the ſun, we ſee him paſs over the ſun's diſk like a little round black ſpot. This is called a tranſit of Mercury.

Mercury is ſaid to be 3222 miles in diameter, as calculated from the ſize he appears to the earth, viz. twelve ſeconds; to be thirty-ſeven millions of miles from the ſun; and to move at the rate of 110680 miles per hour: the ſun to him would appear ſeven times as large as to us.

Venus. ♀.

This beautiful planet is diſtinguiſhed in the firmament by her chaſte brilliancy; her light being ſo white as to cauſe ſenſible ſhadow, and ſo vivid that at her greateſt elongations ſhe is viſible in the fulleſt daylight, to the naked eye: her ſurface is ſo free from ſpots, that her diurnal motion is only gueſſed to be twenty-three hours and twenty-one minutes. Her orbit, like Mercury's, is within ours, and therefore we never ſee them oppoſite to the ſun; and ſhe circumſcribes it in 224 days 16 hours and 49½ minutes, at the rate of 80955 miles per hour. Her diſtance from the ſun is about ſeventy millions of miles, and her diameter 8244 miles, found by its ſubtending an angle from the earth of fifty-ſeven ſeconds. Her axis is ſaid to incline ſeventy-five degrees from the axis of her orbit: and hence the reaſon why ſhe has two ſummers and two winters at her equator; why her tropics are much nearer her poles than ours; why her ſeaſons increaſe and decreaſe faſter than ours; and why ſhe has ſeldom her forenoon and afternoon both of a length. The ſun, however, by paſſing ſo ſwiftly from one of her tropics to the other, gives the heated places time to cool; and this, no doubt, is wiſely calculated for the good of her inhabitants.

This planet is ſometimes a morning, and ſometimes an evening ſtar, as may be ſeen by fig. 3, Plate XLVIII. where S is the ſun, E the earth, and *a b c d e f* the orbit of Venus, and the direction in which ſhe revolves round the ſun. When ſhe is at *a*, ſhe will be ſeen from the earth at *k*, a little to the eaſt of the ſun, or juſt above the weſtern horizon, when the ſun ſets: when at *b*, ſhe will be ſeen at *m*, a little higher, when the ſun ſets: when ſhe gets to *c* (her greateſt elongation), ſhe will be ſeen at *n*, forty-ſeven degrees above the ſun when he ſets, and where ſhe will ſeem ſtationary for a few days; becauſe ſhe is then coming towards the earth pretty nearly in a line. As ſhe advances towards *d*, ſhe will be ſeen to come nearer and nearer to the weſtern horizon every evening when the ſun ſets; and at *e* ſhe will be inviſible (her dark ſide being towards us), except we meet her in the node, when ſhe would tranſit the ſun's face like a little black ſpot. All this time ſhe has been an evening ſtar. She has now paſſed by the ſun, and we ſee her at *s*, a little before the ſun riſes. When ſhe gets to *t*, we ſee her at *u* conſiderably before the appearance of the ſun. At *f* ſhe comes to her greateſt apparent diſtance from the ſun to the weſt, and is then nearer and nearer to him every morning, at *g*, *n*, &c. till ſhe again paſſes behind him between *s* and *k*. So far we have conſidered the earth as ſtanding ſtill at E: but it is paſſing forwards towards *z*; and ſhews why Venus is longer a morning than ſhe is an evening ſtar. During this revolution, we ſometimes ſee more and ſometimes leſs, of her enlightened ſide, like the moon. When at *a* we ſee almoſt a full Venus; at *b* ſhe is gibbous; at *c* ſhe is like a little half-moon; from *c* to *d* ſhe grows more and more a creſcent and at *e* quite dark; at *s* we ſee the thick part of the creſcent towards the eaſt; and being now ſo near the ſun, ſhe is obſerved in the day, &c. &c. To the inhabitants of this planet the ſun will appear twice as large as to us; and Mercury will be a morning and an evening ſtar to them as Venus is to us. Her atmoſphere has alſo been calculated as fifty miles in height, from a ſhade appearing about five ſeconds upon the ſun's face, before the dark body of Venus ſeemed to touch his edge, at the time of her tranſit.

The Earth ⊖ *and Moon* ☽.

Having devoted a lecture to this third planet in the order of the ſyſtem, and its ſatellite the moon, we paſs by them here, and aſcend to

Mars. ♂.

This planet is known in the heavens by a duſky-red appearance: and as the red part of light has only momentum enough to pierce through a groſs or thick medium, and as a duſkineſs appears over thoſe ſtars that he paſſes near, a groſs atmoſphere is ſuppoſed to occaſion this appearance. When he is oppoſite to the ſun, or when we ſee him near the meridian about midnight, he is much more brilliant than in another ſituation (being five times nearer to us than at the conjunction); a large ſpot is then diſtinctly ſeen on his face, by which his diurnal motion is aſcertained to be in twenty-four hours thirty-nine minutes and twenty-two ſeconds. His year is nearly two of ours, being 686 days 23 hours 30¾ minutes. Hence we ſee an analogy between this planet and the earth, a little ſtriking, in their diurnal motion being nearly the ſame; and in his orbit being nearer in the ſame plane with ours than any other, croſſing it only at an angle of one degree fifty-one minutes. It is rather ſurpriſing that he ſhould have no moon; as he is almoſt twice the diſtance from the ſun that we are: perhaps the height and refractive power of his atmoſphere may prolong the ſun's light. To Mars the ſun would appear one third leſs in diameter than to us, being 144 millions of miles from him; and his apparent diameter at the earth being but 27″, his real diameter will be 4189 miles: our earth would appear a ſtar to Mars, about the ſize that Venus appears to us; and never above 48 degrees from the ſun. His figure, fig. 4, Plate XLVIII. is alſo oblate, the equatorial being to the polar diameter as 131 to 127.

Jupiter. ♃.

The next of the ſuperior planets is Jupiter; the largeſt in the ſyſtem, being 90228 miles in diameter, though to the eye he appears not ſo large as Venus; nor does he ſubtend ſo large an angle at the earth as Venus, his being but 40″. This vaſt planet is five times as far from the ſun as we are; and has, therefore, but a twenty-fifth part of the light, heat, or gravitation, that we have. He turns on an axis perpendicular to the plane of his orbit, in nine hours and fifty-ſix minutes; by which his days and nights are of an equal length, and never vary. He has, from the ſame cauſe, no variety of ſeaſons: it being perpetual ſummer near his equator, and perpetual winter towards his poles. From the exceſſive ſwiftneſs of his rotation on his axis, his equatorial diameter has ſwelled ſo as to make him a much more oblate figure than the earth; by which it is thought his clouds and vapours are thrown more immediately up to his equator, and appear like ſtreaks or belts, round him: this is made probable from their frequent change in number and ſituation: when their number is moſt conſiderable, one or more dark ſpots frequently appear between the belts, and diſappear as they do. The remarkable ſpot, by the motion of which Jupiter's rotation on his axis was determined, appeared in 1694, and was loſt till the year 1708, when it re-appeared, on the ſame part of his face, and has been occaſionally ſeen ever ſince. The ſpots and belts ſeen the 7th of April, 1792, with a ſeven-feet Newtonian teleſcope, are exactly repreſented fig. 8, Plate XLIX. Some alſo ſuppoſe theſe belts to be ſeas, and that thoſe variations are occaſioned by tides differently affected, according to the poſitions of his moons.

This noble planet is ſplendidly accompanied; having four ſatellites, or moons, attending him on his journey round the ſun, which he performs in 11 years 314 days and 10 hours, at the diſtance of 499750000 miles from him. The periods of Jupiter's ſatellites are,

	D.	H.	M.	S.
1ſt ſatellite revolves in - - - -	1	18	27	34
2d - - - - - - - -	3	13	13	42
3d - - - - - - -	7	3	42	36
4th - - - - - - -	16	16	32	9

Theſe four moons perform their revolutions round him with ſuch exactneſs, that could we make correct obſervation of them at ſea, we ſhould have no occaſion for time-keepers, or offers of thouſands for finding the longitude; the eclipſes of Jupiter's ſatellites would develope that deſideratum beyond the correctneſs of any time-keeper. But how?—Were there a flaſh of lightning, or any other inſtantaneous phænomenon, to happen, ſo high above the earth, that half the globe could ſee it at once, the longitude of the place of each obſerver would be eaſily aſcertained. By longitude is meant the diſtance eaſt or weſt that one place lies from another. So, if I ſaw the flaſh of lightning at twelve by my clock, at the inſtant another ſaw it at one, then does the latter lie fifteen degrees eaſt of the former; becauſe the earth turns fifteen degrees every hour upon its axis from weſt to eaſt. If another ſaw the flaſh at ten which I ſaw at twelve, then is he two hours behind me, or twice fifteen degrees to the weſt of me. If another ſaw the flaſh at ſeven in the morning, when by my clock it was twelve, the perſon was five hours behind me, or five times fifteen degrees to the weſt of me, or ſeventy-five degrees. Now the eclipſes of Jupiter's ſatellites afford thoſe inſtants, when ſeen through a good teleſcope. Call S the ſun, fig. 7, Plate XLVIII. E the earth, *a* the planet Jupiter, and *b* his firſt, or neareſt ſatellite, juſt dropping into the ſhadow of Jupiter, and inſtantly loſing its borrowed light. Now, ſuppoſe a perſon in the woods of North America wiſhful to aſcertain the longitude of the place, or, in other words, how many degrees the meridian of Greenwich was from the meridian of the place where he was. We may ſuppoſe him poſſeſſed of the Nautical Ephemeris, in which the exact time of every eclipſe of Jupiter's ſatellites is ſet down for the meridian of Greenwich, for many years beforehand. On the night he purpoſes to obſerve, he ſees the firſt ſatellite *b* will be eclipſed at ſix in the morning to all who are on the meridian of Greenwich; but being ſo far to the weſtward, he determines to watch late at night; and at twelve o'clock he ſees the eclipſe take place along the line xii *b*, at the ſame inſtant the people of London ſee it along the line vi *b*. Now, as the earth turns fifteen degrees upon its axis every hour, and as there is ſix hours' difference, it is evident he lies ſix times fifteen, or ninety, degrees weſt of Greenwich, which would be the true longitude of the place to be put on a map or globe. The motion of a ſhip has hitherto prevented this ſimple method of finding the longitude at ſea from being effectual; and hence the large premiums offered for a clock or watch that would keep time with the ſun in all climates. The uſe of ſuch an inſtrument would be to ſet it with the ſun at the place whence a ſhip was to ſail; as ſuppoſe the Lands End, the ſhip bound for Quebec. Now, if the ſhip ſails at twelve o'clock, due weſt, the obſerver will find next day at twelve his watch and the ſun not together: by his quadrant he will find, perhaps, the ſun on his meridian, when the watch is at one o'clock. It muſt be obſerved, that the watch keeps the time of the place he departed from; and therefore, that place paſſing the ſun ſooner than the place where he is, will make a difference in the time pointed out by the ſun and the watch. If an hour, as above, he is fifteen degrees to the weſt of the Land's End. The wind continues fair, and next day, when the ſun is on his meridian, he finds it two o'clock by his Land's-End watch; ſo that in two days' ſailing, the clock and the ſun differ two hours, or twice fifteen degrees; therefore he is now thirty degrees weſt of the Land's-End. Thus, a time-keeper that would go exactly with the ſun, would make the art of finding our way upon a trackleſs ocean of no difficulty; for finding the latitude by the ſtars and the ſun is made eaſy by tables. And thus, if we can know by obſervation, how far we are to the eaſt, the weſt, the north, or ſouth, of the place we ſail from, our track and ſituation can be marked on a chart, juſt as roads are upon a common land map. But heat and cold, moiſture and dryneſs, imperfections of contrivance, and workmanſhip, all conſpire to render this machine incorrect; ſo that we are ſtill obliged to reſort to celeſtial motion for finding the longitude. The moon, from the ſwiftneſs of her motion, is the beſt adapted for this important purpoſe. Her approach to, and recedence from, remarkable fixed ſtars, is, at preſent, our only exact means of finding how far we are eaſt or weſt from the meridian of Greenwich, or any given place. The moon's diſtance from the ſun, from α Arietis, from Aldebaran, from Pollux, Regulus, α Aquilæ, α Pegaſi, &c. calculated for every three hours, gives the longitude in time; which (as above) is eaſily reduced to degrees, and, of courſe, to miles. For example; I hold my quadrant flat, or on a level with the moon and the ſtar for obſervation; I find in the Nautical Almanac they will be diſtant from each other 75° at twelve this night: I watch with my quadrant and time-keeper, and at three in the morning, I find them juſt *that* diſtance. Why then it is evident, from what has been ſaid, that I am three times 15° to the eaſt of the meridian of Greenwich, or my longitude is 45° eaſt. The manner in which theſe are placed in the Nautical Ephemeris is thus:

Diſtance of the Moon's centre from the Sun, and Stars eaſt of her.

Star's Names	Days	Noon	iii hours	vi hours	ix hours	Midnight	xv hours	xviii hrs.	xxi hours
		D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.	D.M. S.	D. M. S.	D. M. S.
α Pegaſi	17	67 13 19	65 45 12	64 0 32	62 16 22	60 32 43	58 49 37	57 7 7	55 25 14

As the aſtronomical day begins twelve hours later than the civil day, i. e. at twelve at noon, and is counted twenty-four in ſucceſſion; we ſee in the above table that the ſtar α Pegaſi, on the 17th of June, will, at midnight, at Greenwich, be 60° 32′ 43″ eaſt of the moon; at fifteen o'clock it will be 58° 49′ 37″ eaſt of the moon, &c. Now if thoſe diſtances are found by the ſextant, at a time different from the table, the longitude of that place is alſo found. Suppoſe I ſee α Pegaſi 62° 16′ 22″ at eleven at night, inſtead of nine, as in the table; then am I two hours to the eaſt of Greenwich, or twice 15°, and my longitude is 30° eaſt. Allowance, however, in this calculation muſt be made for refraction and parallax, agreeable to what has been formerly explained, which may be found in what is called the Requiſite Tables, and other books of navigation. Though the cauſe of the refractive power of the atmoſphere has been explained in the optical lecture, the ratio in which that refraction increaſes from the zenith to the horizon has not been ſtated. Here follows a table of the refractions which the light of the ſun, moon, and ſtars, ſuffers at different altitudes.

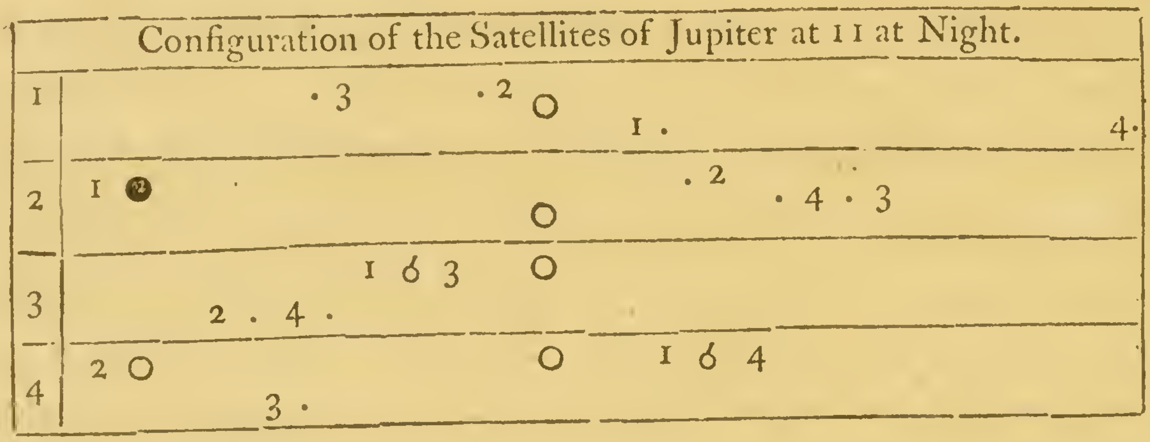
Appar. Alt.		Refrac- tion.		Appar. Alt.		Refrac- tion.		Appar. Alt.		Refrac- tion.		Appar. Alt.		Refrac- tion.	
D.	M.			D.	M.			D.	M.			D.	M.		
0	0	33′	45″	13	0	3′	47″	39	0	1′	6″	65	0	0′	25″
0	15	30	24	14	0	3	31	40	0	1	4	66	0	0	24
0	30	27	35	15	0	3	17	41	0	1	2	67	0	0	23
0	45	25	11	16	0	3	4	42	0	1	0	68	0	0	22
1	0	23	7	17	0	2	53	43	0	0	58	69	0	0	21
1	15	21	20	18	0	2	43	44	0	0	56	70	0	0	20
1	30	19	46	19	0	2	34	45	0	0	54	71	0	0	19
1	45	18	22	20	0	2	26	46	0	0	52	72	0	0	18
2	0	17	8	21	0	2	18	47	0	0	50	73	0	0	17
2	30	15	2	22	0	2	11	48	0	0	48	74	0	0	16
3	0	13	20	23	0	2	5	49	0	0	47	75	0	0	15
3	30	11	57	24	0	1	59	50	0	0	45	76	0	0	14
4	0	10	48	25	0	1	54	51	0	0	44	77	0	0	13
4	30	9	50	26	0	1	49	52	0	0	42	78	0	0	12
5	0	9	2	27	0	1	44	53	0	0	40	79	0	0	11
5	30	8	21	28	0	1	40	54	0	0	39	80	0	0	10
6	0	7	45	29	0	1	36	55	0	0	38	81	0	0	9
6	30	7	14	30	0	1	30	56	0	0	36	82	0	0	8
7	0	6	47	31	0	1	28	57	0	0	35	83	0	0	7
7	30	6	22	32	0	1	25	58	0	0	34	84	0	0	6
8	0	6	0	33	0	1	22	59	0	0	32	85	0	0	5
8	30	5	40	34	0	1	19	60	0	0	31	86	0	0	4
9	0	5	22	35	0	1	16	61	0	0	30	87	0	0	3
9	30	5	6	36	0	1	13	62	0	0	28	88	0	0	2
10	0	4	52	37	0	1	11	63	0	0	27	89	0	0	1
11	0	4	27	38	0	1	8	64	0	0	26	90	0	0	0
12	0	4	5												

This eſtimate has its exceptions; for when the air is in a very denſe ſtate, its refractive powers are greater; and in a rarefied or lighter ſtate, leſs. Moiſture and rain increaſe its refractive power; and cold to a very great degree; inſomuch, that ſome Hollanders, who wintered in Nova Zembla, and had a continual night of three months, found the ſun appear to them ſeventeen days ſooner than by computation he ought; which muſt have ariſen from the ſun's rays paſſing through the cold denſe air of that climate. Why a greater refraction takes place near the horizon than the zenith, may be ſeen by fig. 5, Plate XLVIII. where E is a ſemi-earth, S the ſun in the zenith to a perſon ſituated at *a*. The dark ſhade repreſents the earth's atmoſphere, through which the ray S *a* paſſes perpendicularly, and without refraction; (ſee Optics). But to a ſpectator at *c*, the ſun would be ſeen at *i*, for the ray S *n* is bent at *n* into the direction *n c*; and as we ſee every thing along that line in which the rays from it came laſt, we ſee the ſun along the line *c n i*. The obſerver at *g* ſees the ſtationary ſun S at *k*; for there the refracted ray *z g* is more bent: but the obſerver in the horizon at *s*, has the ray S *r* falling ſtill more obliquely upon the atmoſphere, and bent in the direction *r s*; and hence he ſees the ſun S at *m*, under the greateſt refraction.

But to return to Jupiter. His ſatellites do not revolve round him in the ſame plane; nor are their nodes in the ſame place: the firſt ſatellite inclines 2° 55′ from the plane of Jupiter's orbit, and its aſcending node is in the middle of Aquarius ♒. This ſatellite is the moſt important of the four, from its numerous eclipſes, having often eighteen or twenty in one month, for its period round Jupiter is only forty-two hours twenty-ſeven minutes thirty-four ſeconds, and diſtance one minute and fifty-one ſeconds. But to form an idea of the track which all the ſatellites make through the heavens, as they accompany Jupiter on his annual journey, ſee fig. 8, Plate XLVIII. where the progreſs of ſixteen days is depicted, and figures annexed. Let Jupiter be at *a*, and his four ſatellites in conjunction. Now, while he travels from *a* to 1, his firſt ſatellite will travel to 1; and while Jupiter travels from 1 to 2 (his ſecond day's journey), the firſt ſatellite travels from 1 to 2, having made a *loop* below the orbit of Jupiter; ſo that the configuration the firſt day after the conjunction would be as in the figure, viz. the firſt ſatellite would be ſeen on the left of Jupiter, and the other three on the right: for it muſt be ſuppoſed we are looking at them on a level with the ecliptic; or as if we took the paper that contains the figure, and held its edge to the eye,

It is curious to obſerve in this figure, that the three firſt ſatellites come nearly into conjunction every ſeventh day: in that time, the firſt ſatellite has made four revolutions round the planet; the ſecond ſatellite, two revolutions; and the third ſatellite, one. In the next ſeven days, it may be ſeen, the fourth ſatellite comes nearly to the weekly rendezvous; but he moves ſo wide as to be ſeldom eclipſed, or in conjunction. By this figure may be ſeen how Jupiter and his moons have their configuration in the Nautical Ephemeris: thus,

Configuration of the Satellites of Jupiter at 11 at Night.



On the firſt of the month, at 11 at night, the 2d and 3d ſatellites are on the left of Jupiter; and the 1ſt and 4th on the right: it may be ſeen alſo, that there is obliquity in their orbits; that the 2d and 3d are in northern latitude, while the 1ſt and 4th are in ſouthern latitude.

On the ſecond day, at the ſame hour, the 1ſt ſatellite is in eclipſe;

and the 2d, 4th, and 3d, on the right of the planet. On the third day, at the ſame hour, the 2d and 4th are on the left of the planet, while the 1ſt and 3d are ſo much in a line, or in conjunction, that they appear but as one. On the fourth day, at the ſame hour, the 2d ſatellite would be ſeen like a bright ſpot on the diſk of Jupiter; the 3d, on his left; and the 1ſt and 4th, in conjunction, on his right. The moons of Jupiter turn round him the ſame way he turns on his axis, in the order of the ſigns: ſo that when we ſee a ſatellite beyond Jupiter, as it were, its motion is direct; as from *a* by *b* to *c*, fig. 6, Plate XLVIII. But when it moves from *c* by *d* to *a*, its motion appears retrograde: hence, they all ſeem to vibrate from one ſide of him to its oppoſite, ſome moving direct, and others retrograde.

Jupiter himſelf has one retrograde and two ſtationary appearances every thirteen months: for in that period we always paſs by him. Let *a* repreſent Jupiter, fig. 1, Plate XLIX. and *e* the earth: now, while the earth is moving from *e* to *m*, Jupiter will appear ſtationary at *x*; but while the earth moves from *m* to *n*, the planet will have appeared to go backward from *x* to *z*; and while the earth moves from *n* to *q*, the planet will appear retrograde from *z* to *r*: but while the earth moves from *q* to *s*, Jupiter will again ſeem ſtationary at *r*. This is a ſtrong and clear proof that the earth is not the centre round which the heavenly bodies revolve; for were that the caſe, the retrograde and ſtationary appearances of the planets had never exiſted. But if the earth be a planet among the reſt, moving faſter than the ſuperior planets, and ſlower than the inferior, thoſe appearances muſt take place; as it would be in two unequal ſailing ſhips going the ſame way; to the ſwifter, the ſlower would appear to ſtand ſtill or to go backward.

When we are in that part of our orbit neareſt to Jupiter, we ſee the eclipſes of his ſatellites ſixteen minutes ſooner than when in the remoteſt part; proving light to be progreſſive, and that its influence comes from the ſun to us in about eight minutes. This was firſt obſerved in thoſe parts of the earth's orbit which lie in the ſame line with Jupiter, as *e* and *m*, fig. 1, Plate XLIX. Now, if the effect of light were inſtantaneous, an eclipſe at Jupiter would happen at *e* at the ſame time as at *m*; but the moſt common obſervation will prove it is not ſo; but that the eclipſe is ſeen ſeveral minutes ſooner at *m* than it would be at *e*. Beſides, the inſtant when any of theſe eclipſes will happen is eaſily determined by calculation; becauſe the times in which they perform their revolutions are known; and therefore, if they take place ſixteen minutes ſooner when the earth is neareſt to Jupiter than when it is in the fartheſt part of its orbit from him, it is evidently occaſioned by the time which light takes up in being put in motion acroſs the diameter of the earth's orbit.

With what inconceivable velocity muſt light impel light through ſuch an amazing extent of ſpace! ninety-five millions of miles in eight minutes! a million of times ſwifter than a cannon ball!—the mind ſhrinks from the purſuit of ſuch an idea.

Even as to the fixed ſtars, it was long ſuſpected that they were ſeen a little differently in their ſituations at one time, in our annual journey round the ſun, than they were at another. Bradley obſerved in a zenith ſector, or perpendicular teleſcope, the ſtar γ Draconis in a different part of the field of the inſtrument at one part of the year than it was in another; and ſoon conceived that this appearance muſt ariſe from the progreſſive motion of light: which may be thus explained. Suppoſe *a b*, fig. 1, Plate XLIX. a part of the earth's orbit, and that a ſpectator at *a* were obſerving the ſtar *c*; and that the motion of light was to the motion of the earth as the line *c b* to *a b*; then by the time the earth had travelled from *a* to *e* light would have been impelled from *c* to *g*, and the ſtar would be ſeen at 1. When the earth got to *i*, light would have fallen to *z*, and the ſtar would be ſeen at 2; ſo that when the earth arrived at *b*, the ſtar would be ſeen at *d*. Or ſuppoſe a drop of rain were to fall through the inclined tube *a b*, fig. 3, Plate XLIX.; it is evident, that if the tube were puſhed from *b* to *c*, while the drop would fall from *a* to *c*, that the drop would fall through the tube without touching its ſides. So it would be with a particle of light; that when the tube arrived at *c*, the particle would be ſeen at *d*. This is called the aberration of light; and proves that particles of light are ſtreaming from every ſtar in the heavens, and that the immenſity of ſpace is filled with moving light in all directions.

Jupiter's equatorial diameter is 6000 miles more than his polar diameter; or they are to each other as thirteen to twelve. His orbit is inclined to the ecliptic only 1° 20′. His aphelion (or place where he is fartheſt from the ſun) is the 9° 10′ of Libra, and that is but $\frac{1}{20}$ of his mean diſtance from the ſun. His aſcending node is the 7° 29′ of Cancer; and deſcending node of courſe the ſame in Capricorn. This planet, ſeen from his neareſt moon, would appear 1000 times as large as our moon does to us; increaſing and waning like her, every forty-two hours. An obſerver from Jupiter would ſee two kinds of planets; four near him (i. e. his ſatellites), and two remote, viz. the Sun and Saturn: but the ſun would appear but the 48th part ſo large to him as to us. Since the appearance of the great comet in 1682, Jupiter has not moved through the ſame track in the heavens, as before that time: and as the comet croſſed his orbit near where he was at the time, it is natural to ſuppoſe the comet had a temporary influence upon him, and that the ſubſequent deviation was occaſioned by it. But as the diſorders of nature carry their own ſelf-phyſic along with them, that deviation would gradually diminiſh; and accordingly we now find Jupiter approaching very nearly to the ſame track he purſued before the year 1682.

Saturn ♄.

This ſtupendous planet deceives the eye, by its pale and feeble light; for, next to Jupiter, it is the largeſt in the ſyſtem. It ſubtends an angle at a mean diſtance from our globe of 18″; and is 29 years 167 days and 6 hours in going round the ſun. From theſe data, his diameter is calculated to be 79979 miles, and his diſtance from the ſun 916,500,000 miles. His diurnal motion is not yet well aſcertained; being ſo remote, and his ſpots are ſo ill defined; though it is ſaid to be in ten hours and ſixteen minutes. Five ſatellites were diſcovered many years ago; and lately, two more have been added to the five: beſides theſe, a large broad, double, and luminous ring ſurrounds his orb, which muſt add greatly to the light derived from his ſeven moons. This vaſt ring muſt appear to his inhabitants like a diſtant and immenſe arch of light in the heavens, and was probably intended to aſſiſt the imperfect light to which he is ſubjected by his diſtance from the ſun. With theſe aſſiſtances, and the ſun's original light, which is computed to be 500 times the light we have from our full moon: though his light and heat is ſo far inferior to ours, no doubt the eyes and conſtitution of his inhabitants are adapted to them; and that he may be as comfortable an abode as the worlds that are more enriched with thoſe bleſſings. Saturn appears through a teleſcope of 400 magnifying power of the ſize and figure of fig. 5, Plate XLIX. In this may be ſeen the ſhadow of the planet on the lower part of the double ring; and a ſpot between two belts. Sometimes he appears like fig. 6, Plate XLIX. and of that ſize, ſeen through an ordinary teleſcope. This ring is calculated to be 204883 miles in diameter, ſurrounding Saturn at a diſtance equal to its breadth: it inclines about thirty degrees to the plane of the ecliptic; and by roughneſſes on the edge, can be perceived to turn on an axis perpendicular to its plane, in eleven hours. With this inclination, it keeps parallel to itſelf, as fig. 7, Plate XLIX. during the thirty years' revolution of Saturn round the ſun. It is plain, therefore, that twice in this journey, viz. every fifteen years, the plane of this ring will be with its edge towards us; and then it will appear like a line over the body of the planet, reaching ſome diſtance on each ſide of it, as at *a* and *b*. If this ring be opaque, as the ſun ſhines fifteen years on its north, and the ſame time on its ſouth ſide, it will have equal day and night; each fifteen years long. This may be better underſtood by the fig. 7, Plate XLIX.

The fifth ſatellite of Saturn evidently turns on its axis, as it varies in brightneſs in proportion as it advances in its orbit; and it is probable all the reſt do the ſame: their periods round the planet are—

	d.	h.	m.	s.
1ſt ſatellite in - - -	1	21	18	27
2d - - - - - - -	2	17	41	22
3d - - - - - - -	4	12	25	12
4th - - - - - - -	15	22	41	12
5th - - - - - - -	79	7	47	0

The periods of the two late diſcovered ſatellites are,

	d.	h.	m.	s.
6th - - - - - -	1	8	53	9
7th - - - - - -	-	22	40	46

The ſwiftneſs of Saturn's motion on his axis produces an oblate figure; ſo that his equatorial diameter is calculated to be to his polar diameter, as 11 is to 10.

Georgian Planet, or the Herſchel.

This planet was diſcovered by Dr. Herſchel, in March, 1781. From the ſlowneſs of its motion, aſtronomers had miſtaken it for a fixed ſtar: Flamſtead made it the 34th ſtar in Taurus; and the diſcoverer at firſt ſuppoſed it to be a comet. It was found nearly in a line with Caſtor and Pollux, and ſo near the ecliptic, as naturally ſuggeſted a ſuſpicion of its being a planet. Its regular motion was ſoon diſcovered, which removed all doubts of its being a planet; particularly when it was found to be accompanied with two ſatellites. Subſequent obſervations have added four more, two of which are ſaid to move in a retrograde motion, or contrary to the order of the ſigns *. It is calculated by M. de la Lande to be eighty-nine times larger than the earth; to be nineteen times further from the ſun than the earth; and that its year is the length of eighty-two of ours. The apparent diameter of this planet being but four ſeconds, it can only be ſeen by the naked eye in the abſence of the moon: it is of a blueiſh-white colour, and well defined, when ſeen through a teleſcope of a conſiderable magnifying power.

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* This I rather think is but in appearance; for if the declination of the ſatellite be greater than its latitude, it will have a retrograde appearance.

The periods of its ſatellites are as follow:

	d.	h.	m.	
1ſt, or neareſt, in	5	21	25	late diſcovery.
2d - -	8	18	0	diſcovered ſome time ago.
3d - -	10	23	4	late diſcovery.
4th - -	13	12	0	diſcovered before.
5th - -	38	1	49	late diſcovery.
6th - -	107	16	40	ditto.

COMETS.

THESE ſeven primary planets, and the eighteen ſecondary ones, or moons, are conſidered as the regular bodies of the ſolar ſyſtem: they move pretty nearly on the ſame level, and in the ſame direction. But the ſyſtem is ſometimes viſited by other bodies, which approach the ſun in all directions. Theſe are called comets; from their having generally a ſtream, or hair-like appendage, adhering to them. The various opinions of the learned, reſpecting thoſe wonderful bodies, would fill a volume. Halley conceived them to be planets, moving in very eccentric orbits, but deſcribing equal areas in equal times, and therefore having their periods reducible to calculation. He contends for the comet of 1682, of 1607, of 1456, and 1305, being one and the ſame; and that the difference in theſe periods was occaſioned by the attraction of Jupiter, as the path of the comet lay near him; but that it would appear again in the year 1758. A ſmall comet was thought to be ſeen at that time, by a few obſervers in France, but ſo unlike the comet of 1682, in ſize and duration, that it was impoſſible to be conceived the ſame. We have been looking out for another theſe ten years, that ſhould have appeared according to the above calculation, but it has not yet appeared. When we find ſuch excellent aſtronomers and mathematicians, as Dr. Halley, miſtaken, I fear we muſt ſuſpect that the motion of comets does not come within the ſphere of calculation. Sir Iſaac Newton ſuppoſed the tails of comets a kind of vapoury atmoſphere, rarefied by the ſun, and bruſhed behind the comet by his emanating rays (for the tail of a comet points always from the ſun); and that this moiſture might be intended to ſupply the waſte, occaſioned by vegetation, on the ſeveral planets; and, perhaps, at laſt, the comet might fall into the ſun, and recruit him with freſh fuel. Others have ſuppoſed them capable of being inhabited, notwithſtanding their extremes of heat and cold: that as they approach the ſun the atmoſphere becomes ſo rarefied, as to be incapable of imbibing or retaining heat; and that as they recede from him the atmoſphere wraps more round them, becomes more denſe, and of courſe more ſuſceptible of imbibing heat. Obſerving that the tail of a comet, the aurora borealis, and electrical light, do not refract or bend light that paſſes through them; i. e. that ſtars ſeen through the tail of a comet, and through an aurora, are ſeen in the ſame place, as if there was no ſuch matter between them and the obſerver; it has been ſuppoſed that theſe three phænomena are of one and the ſame kind of matter.

Hevelius ſuppoſes the nucleus, or head of a comet, to be tranſparent; and that the ſun's light paſſing through it, forms the tail. This idea is ingenious; and I ſee nothing in the numberleſs obſervations upon comets, that proves their nucleus opaque. May I hazard a conjecture in ſuch learned company? Many comets have been traced to the ſun, and have not been found to return from him: as many comets have been diſcovered retrograde as direct, in their motion towards the ſun: and it is remarkable that (except the comet of 1744) they have all moved very oblique to the ecliptic;

at great angles, as 36°, 48°, 88°, &c. &c. If concentrated electricity be capable of aſſuming the appearance of a ball of fire, as proved in the Lecture on that ſubject, and that electricity be but ſolar light, in a ſtate of great purity, may not contending light, meeting in ſpace from ſeveral ſuns, form ſuch a condenſation, as to make a ball of embodied light, like the electrical thunderbolt?—That this ball ſhall be tranſparent, and impelled from this meeting by that ſtream of light which is the ſtrongeſt, and forced towards the next ſun? See Plate I.; and fig. 8, Plate XLV. of Aſtronomy.

We have already ſuggeſted that centrifugal light is thrown off from the equatorial part of our ſun, and that its repellency is greateſt there; therefore, the ſun's attraction will be leſs impeded about his poles, and of courſe be greateſt there. Light is attracted by all bodies, where a repellant power is not predominant on their ſurface; therefore light, either in a dilute or concentrated ſtate, may be drawn into the body of the ſun, about his poles, notwithſtanding the atmoſpheric repellency of his equatorial parts. May not this account for the obliquity with which the comets move, reſpecting the ecliptic, and the ſun's equator, and their univerſal tendency towards his poles? May not the obliquity with which they fall towards the ſun, make them ſometimes paſs by him? and by paſſing into his equatorial ſtream be thrown off to a conſiderable diſtance, before the medium becomes dilute enough for the nucleus to diſperſe? and thus the comets to have the appearance of a revolution? Is not the irregularity of their appearance favourable to this conjecture? and is it not probable that meteors themſelves are but ſmaller aſſemblages of concentrated light, which ſoon melt in corruſcations into the general maſs? It may be objected, that light having paſſed through a tranſparent body, would be leſs than the light which ſurrounds it, and therefore that it could not be ſeen. To this I oppoſe fig. 8, Plate XLV. where *m* is the concentrated ball of light, cauſed by the meeting of the ſtreams *s m*, *t m*, &c.: now if the impulſe *n m*, and *t m*, be predominant, the ball will be puſhed towards *s*, ſo far, perhaps, as to come within the attraction of a neighbouring ſun; towards which it will be accelerated, and increaſe in brightneſs; the ſun's rays carrying off a portion of its condenſed light, as it paſſes through it, and thereby increaſing alſo the brightneſs of the tail. That light is liable to this kind of concentration, we ſee in many inſtances; it darts in this ſtate from iron in a white heat, in impalpable balls, that burſt with report and emanation. Balls of electrical light fly through a vacuum; and concentrated lightning frequently aſſumes the appearance of a ball, and has been ſeen to roll along the earth before it burſt. This kind of ball has alſo been produced by the excitation of common electricity. This is but another conjecture added to the many already in being; and it has its difficulties in common with them. No doubt, comets are ordained for ſome wiſe and uſeful purpoſe, in the ſcheme of creation, though we have not yet had penetration enough to find it out.

On the FIXED STARS.

IF from the ſpace allotted for the ſolar ſyſtem, we launch out into that infinity of ſpace that ſurrounds it on all ſides, we may contemplate wonders truly worthy of their divine Author! Whoéver conceives the fixed ſtars to be placed in a concave ſurface, and equally diſtant, as they appear to us, muſt have a limited idea of creation; for one ſtar appears large, another little, becauſe they are placed at immenſe diſtances from each other: it is our limited ſight that makes them appear equi-diſtant; for it is not improbable that the ſmalleſt apparent ſtar is as large as the brighteſt, and only appears ſo from its greater diſtance. By the naked eye we can but ſee about 500 ſtars at once; ſo that all we can ſee in both hemiſpheres, is not much above 1000. This appears extraordinary, becauſe we ſuppoſe we ſee thouſands at once; but this is a deception of our eyes, which running from one ſtar to another multiplies them without end. Select a portion of the hemiſphere, on a clear night, and count the ſtars it contains, and you will be amazed at the ſmallneſs of their number. From this we muſt not ſuppoſe their number really to be ſmall; by teleſcopes 2000 was added to the 1000 ſeen by the naked eye, ſo that ſome time ſince the catalogue of fixed ſtars was about 3000. But by the improvements, made in that inſtrument by Dr. Herſchel, and the unremitting uſe he has made of it (by ſweeping the heavens), not leſs than 30,000 have been added to the former catalogue! Nay, were our glaſſes ſtill better, no doubt we ſhould diſcover more*.

Our teleſcopes have their limits, as well as our eyes, but the ſpace we explore has no limits! Can any one ſuppoſe theſe bodies were only intended to give a faint twinkling light in the night ſeaſon, when thouſands cannot be ſeen by the unaſſiſted eye? And when an additional moon would have been more effectual for that purpoſe,

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* De la Lande has aſcertained the places of 43,400 ſtars, none leſs than of the 7th magnitude; and means to continue his obſervations till he has completed 50,000, an yet to go no farther than the tropic of Capricorn. He apprehends, with the teleſcope with which theſe obſervations were made (viz. an achromatic of two inches aperture), that 300,000 might probably be viſible on the whole ſurface of the heavens; and that the teleſcope of Dr. Herſchel, which has 18 times the aperture, i.e. 324 times the light, would diſcover 90 millions! and no doubt, theſe are very few in compariſon of what exiſts.

than the whole hoſt of heaven? This twinkling appearance, at firſt ſight, diſtinguiſhes the fixed ſtars from the planets, which ſhine by a bright and ſteady luſtre, ſomething like a diſtant candle. The fixed ſtars are mere points to us, from their immenſe diſtance; and therefore the ſmalleſt mote in our atmoſphere will temporarily cover them: theſe perpetually in the air, cauſe this tremulous appearance; particularly near the horizon, where the ſtars twinkle moſt, becauſe we look through a greater portion of the atmoſphere in looking horizontally than in looking upwards. Beſides this, the rays that ſeem to iſſue from a luminous body that is near (as a candle), are the reflection of the ſmooth moiſt ſurface of the eye-lids, that touch one another when we wink. But that cannot be the caſe in looking at a ſtar; for its impreſſion on the retina is a mere point, and it will cauſe vibrations round that point in proportion to the intenſity of its light: the teleſcope magnifying this point, ſtrips the ſtar of thoſe rays. Floating motes do not diſturb the light of a planet, becauſe of the largeneſs of their apparent ſurface.

By means of the zenith ſector, Hook, Flamſtead, and Bradley, obſerved for ſome time the tranſit of γ Draconis over this perpendicular teleſcope; hoping that the diameter of the earth's orbit might make an angle or parallax with it: not at all! The ſtar was ſeen ſo near the ſame place, when the earth was at its ſpring and autumnal equinox (near 200 millions of miles different), that no eſtimate could be made! Bradley gueſſed there might be an angle of about two ſeconds, which would make the fixed ſtars 400,000 times as far from us as the ſun! M. J. Caſſini ſuppoſed the annual parallax of Sirius to be ſix ſeconds, from which it was calculated to be 18,000 times further from us than the ſun. Now, as light (like gravity) diminiſhes as the ſquares of the diſtances increaſe, i.e. if a candle at *a*, fig. 9, Plate XLV. enlightens a ſquare board *c d*, with a given quantity of light, at twice the diſtance, that light is divided into four, ſo on each of the four parts there is but one fourth part of the light, as on *c d*, each of the ſquares being of equal ſize. At three times the diſtance there is but one ninth on each ſquare, as on *c d*; and at four times the diſtance there is but one ſixteenth of the light on each ſquare, as on *c d*, &c. &c. Light, therefore, diminiſhing in this proportion, it is impoſſible that the light of our ſun ſhould reach ſo far as the fixed ſtars, and be from them reflected back with that amazing luſtre with which they ſhine. If then they do not ſhine by borrowed light, as our moon and the planets do, they muſt ſhine, as our ſun does, by their own inherent light, and, by analogy, be ſuns themſelves. But if they are ſuns, by the ſame analogy they muſt be deſtined for the ſame noble purpoſe as our ſun; to give light, heat, and vegetation, to various worlds that revolve round them, but which are infinitely too remote to be perceived by us, though aſſiſted by our greatly-improved teleſcopes! How much too vaſt for the human mind is this idea! But the idea muſt be carried ſtill further: for we ſee every particle of our globe ſwarm with life and animals; and can we ſuppoſe ſuch bodies as compoſe the reſt of our ſyſtem made for nothing but for mortals to gaze at? They turn as regularly on their axes, and perform their annual revolutions, with equal preciſion as our earth. Many of them have ſummer and winter, ſpring and autumn, as well as the earth; and three of theſe planetary worlds abound with moons to aſſiſt their light. Do not theſe ſimilar attributes imply a ſimilar uſe with that of the earth? and that we may conclude thoſe worlds to be inhabited?

The analogy goes ſtill further. We ſee our ſun turn on his axis. The fixed ſtars Algol, β Lyra, δ Cephei, η Antinoi, ο Ceti, &c. * are known to turn in like manner, by their growing periodically darker and brighter, in ſtated times. Muſt not theſe revolutions be for the purpoſe of throwing off centrifugal light to the worlds that ſurround thoſe ſuns; cauſing their motions, and diffuſing all-chearing light through ſpace?

Aſtronomers divide the heavens into three regions—a northern and a ſouthern hemiſphere, and the zodiac. Stars of various magnitudes are ſeen in all theſe regions, and are claſſed into conſtellations of variety of figures, as men, quadrupeds, fiſh, &c. Theſe figures are ſaid to have originated with the ancient Chaldeans, or Egyptians; but ſome of them being found on the ruins of pagodas and obſervatories in Hindoſtan, they ſeem, like moſt other ſciences, to have ſprung from the Eaſt. The Egyptians were remarkable for their hieroglyphics, and allegories. Poverty in language, always begets poetry. Where there are not words to expreſs ideas, mankind have recourſe to alluſion, to allegory, and ſymbols. Of that deſcription are the figures we find on ancient charts of the heavens; and which are copied on our celeſtial globes. The idea was grand and ingenious! The tenets and myſteries of a mythology were thus regiſtered upon the face of the heavens; a book, eternal (to our ideas at leaſt), and that all mankind could ſee. The Greeks, ſtruck with the magnificence of the idea, diſplaced many of the Chaldaic con-

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* Algol revolves in three days; β Lyra, in five days; δ Cephei, in ſix days; η Antinoi, in ſeven days; ο Ceti, in 331 days; Hydra, in 394 days; the bright ſtar in the neck of the ſwan, in 497 days; α Hercules, ſixty days. This periodical diminution of light and diſappearance, with the re-appearance and augmentation of light, in many of the fixed

ſtellations, and inſerted much of their own fable and poetic theology: hence we find Hercules, Perſeus, Caſtor, Pollux, &c. &c.

Many ſtars of remarkable magnitude have names beſide the conſtellations of which they make a part; many of which were given by Arabian aſtronomers, as Aldebaran, Markab, Fomalhaut, &c. which are ſtill retained on our globes. Theſe conſtellations anſwer a convenient end, in the uſe made of them by modern aſtronomers; they form a contour or outline, become a kind of demarcation, by which every ſpot in the heavens can be called by a ſpecific name; and by Bayer's Letters, every ſtar capable of being ſeen by the naked eye has a diſtinct name. The largeſt apparent ſtar in a conſtellation has the firſt letter of the Greek alphabet placed before it; the ſecond in ſize, the ſecond letter, &c.; ſo that though this alphabet is repeated over and over again, yet, being in different conſtellations, the ſtars have each a different name. I ſee α in Orion, and α in the Twins; I call one Alpha Orionis, and the other Alpha Geminorum, &c. Hence, if a comet, or any ſtrange phenomenon, appeared in the heavens, I could write to my correſpondent in China, and direct him to the ſight of it, as well as if I pointed it out with my finger.

ſtars, is referred to ſpots on their ſurface. Some have thought it might be explained by ſuppoſing them of a diſcoid figure, like a plate; ſometimes turning their flat, and at others their narrow and ſharp, ſide towards us. Either ſuppoſition equally connects itſelf with that of a rotation on their axes, to account for the effect.

Northern Conſtellations.

Conſtellations.	Engliſh Names.	Remarkable Stars.	Mag.
Urſa Minor	Little Bear	α Urſa Min. Polar Star	2,3
Urſa Major	Great Bear	α Urſa Majoris	2
Draco	Dragon	γ Draconis	2
Cepheus	- - - -	- - - -	
Bootes	Bear Driver	Arcturus	1
Coma Berenices	Berenice's Hair	- - - -	
Corona Caroli	Charles's Crown	- - - -	
Corona Borealis	Northern Crown	α Coronæ Borealis	2
Hercules	Hercules	α Hercules	2,3
Cerberus	- - -	- - - -	
Lyra	The Lyre	α Lyræ	1
Cygnus	The Swan	α Cygni	
Vulpecula	The Fox	- - - -	
Anſer	The Gooſe	- - - -	
Lacerta	The Lizard	- - - -	
Caſſiopeia	- - -	β Caſſiopeia	2
Camelopardalis	The Cameleopard	- - - -	
Serpens	The Serpent	α Serpentis	2
Ophiuchus	Serpentarius	α Ophiuchi	2
Aquila	The Eagle	Alcair	1
Antinous	- - - -	- - - -	
Delphinus	The Dolphin	- - - -	
Equulus	The Horſe's Head	- - - -	
Sagitta	The Arrow	- - - -	
Andromeda	- - - -	β Andromedæ	2
Perſeus	- - - -	β Perſei. Algol	2
Pegaſus	The Flying Horſe	γ Peg. Algenib	2
Auriga	The Waggoner	Capella. Little Goat	1
Lynx	- - - -	- - - -	
Leo Minor	The Little Lion	δ Leonis Minor	1,3
Triangulum	Triangle	- - - -	
Muſca	The Bee	- - - -	
Taurus Poniatowſki	- - -	- - - -	

Southern Conſtellations.

Conſtellations.	Engliſh Names.	Remarkable Stars.	Mag.
Cetus	The Whale	α Ceti	2
Eridanus	The River	Achernar	1
Phœnix		α Phœnices	2,3
Toucan			
Orion		Rigel	1
Monoceros	The Unicorn		
Canis Minor	Little Dog	Procyon	1
Apus	Bird of Paradiſe		
Hydra	Water Serpent	α Hydræ	2
Sextans	Sextant		
Crater	The Cup		
Corvus	The Crow		
Centaurus	The Centaur	α Centauri	1
Lupus	The Wolf		
Ara	The Altar		
Triangulum	The Triangle	α Trianguli	2,3
Pavo	The Peacock	α Pavonis	2
Corona Auſt.	Southern Crown		
Grus	The Crane	α Gruis	2
Piſces Auſt.	Southern Fiſh	Fomalhaut	1
Lepus	The Hare		
Columba	Noah's Dove	α Columbæ	2
Robur Caroli	Royal Oak		
Crux	The Croſs	α Crucis	1
Argo Navis	The Ship	Canopus	1
Canis Major	Great Dog	Sirius the Dog Star	1
Apis	The Bee, or Fly		
Hirundo	The Swallow		
Chamelion			
Piſces Volans	Flying Fiſh		
Xyphias	The Sword-fiſh		

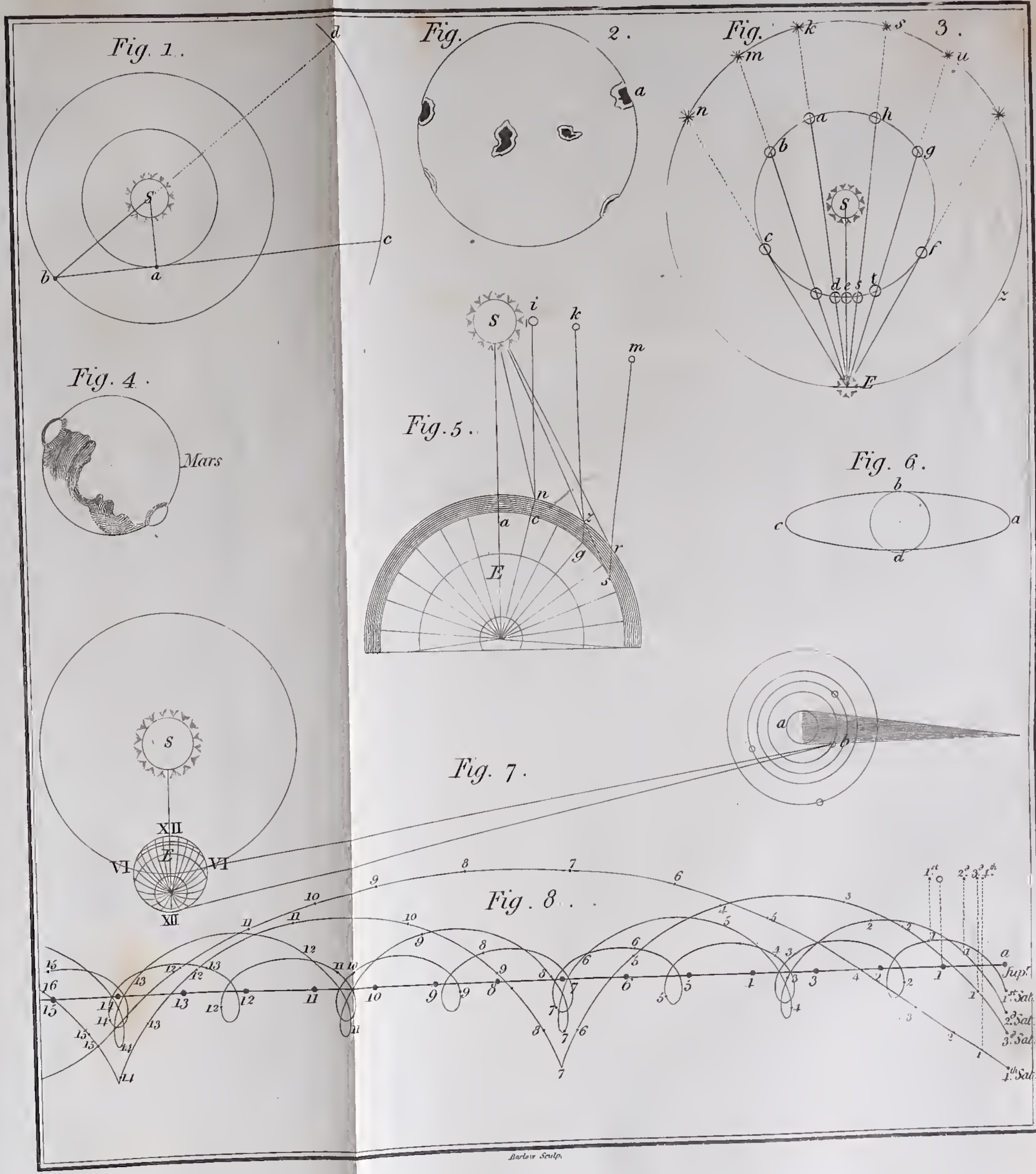
Conſtellations of the Zodiac.

Conſtellations.	Engliſh Names.	Remarkable Stars.	Mag.
♈ Aries	the Ram	α Arietis	2
♉ Taurus	the Bull	Aldebaran	1
♊ Gemini	the Twins	Caſtor and Pollux	1,1
♋ Cancer	the Crab		
♌ Leo	the Lion	Regulus	1
♍ Virgo	the Virgin	Spica	1
♎ Libra	the Scales	α Libræ	2
♏ Scorpio	the Scorpion	Antares	1
♐ Sagittarius	the Archer	ε Sagittarii	2
♑ Capricornus	the Goat		
♒ Aquarius	Water-carrier		
♓ Piſces	the Fiſhes		

When we look on a celeſtial globe, at the ſymbols in the above table, and we find them not to agree with the animals they are meant to repreſent—i. e. that the ſymbol ♈ Aries is forty degrees behind the ram, which it repreſents; Taurus, the ſame; and ſo on through the twelve ſigns—the young aſtronomer would be confounded for a reaſon, if he were not previouſly acquainted with the preceſſion of the equinoxes (ſee page 15). This very extraordinary effect, viz. that the ſun ſhould croſs the earth's equator 50″ of a degree earlier every year, than in the preceding year, and ſo, that the equator ſhall cut the ecliptic a whole degree retrograde in the courſe of ſeventy-two years, makes it neceſſary to have celeſtial globes renewed, at leaſt, every ſeventy-two years; as the longitude of the ſtars (in the zodiac particularly) would, at this time, be a degree wrong on a globe made ſeventy-two years ago, as well as a ſmall matter wrong in declination. For longitude being eſtimated from the firſt point of Aries, to the place where a line from the moon or ſtar would cut the ecliptic perpendicularly, and a perpendicular let fall from the moon or ſtar on the celeſtial equator

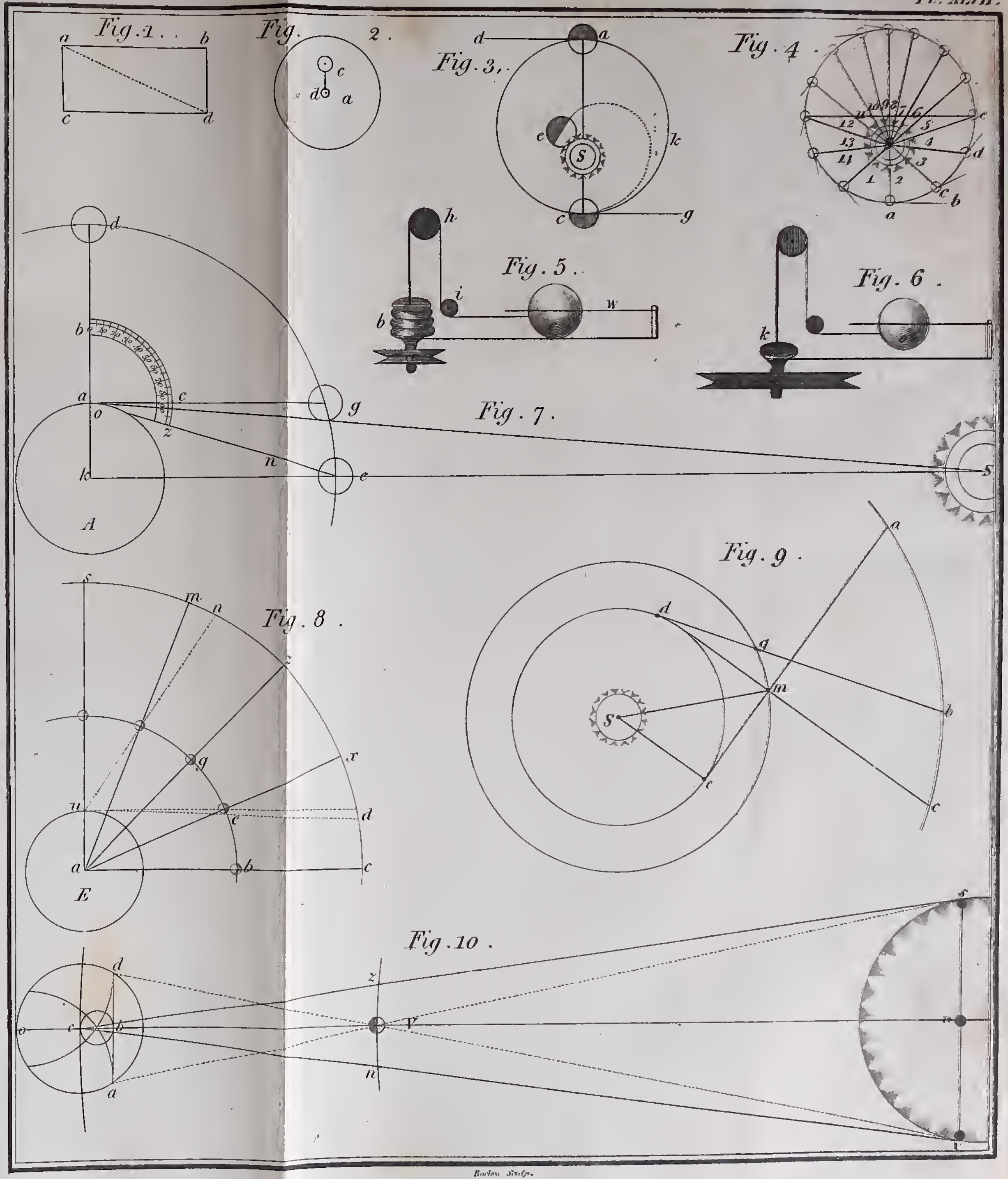
ASTRONOMY.

Pl. XLVIII.



Barlow Sculp.

ASTRONOMY.



Barlow sculp.

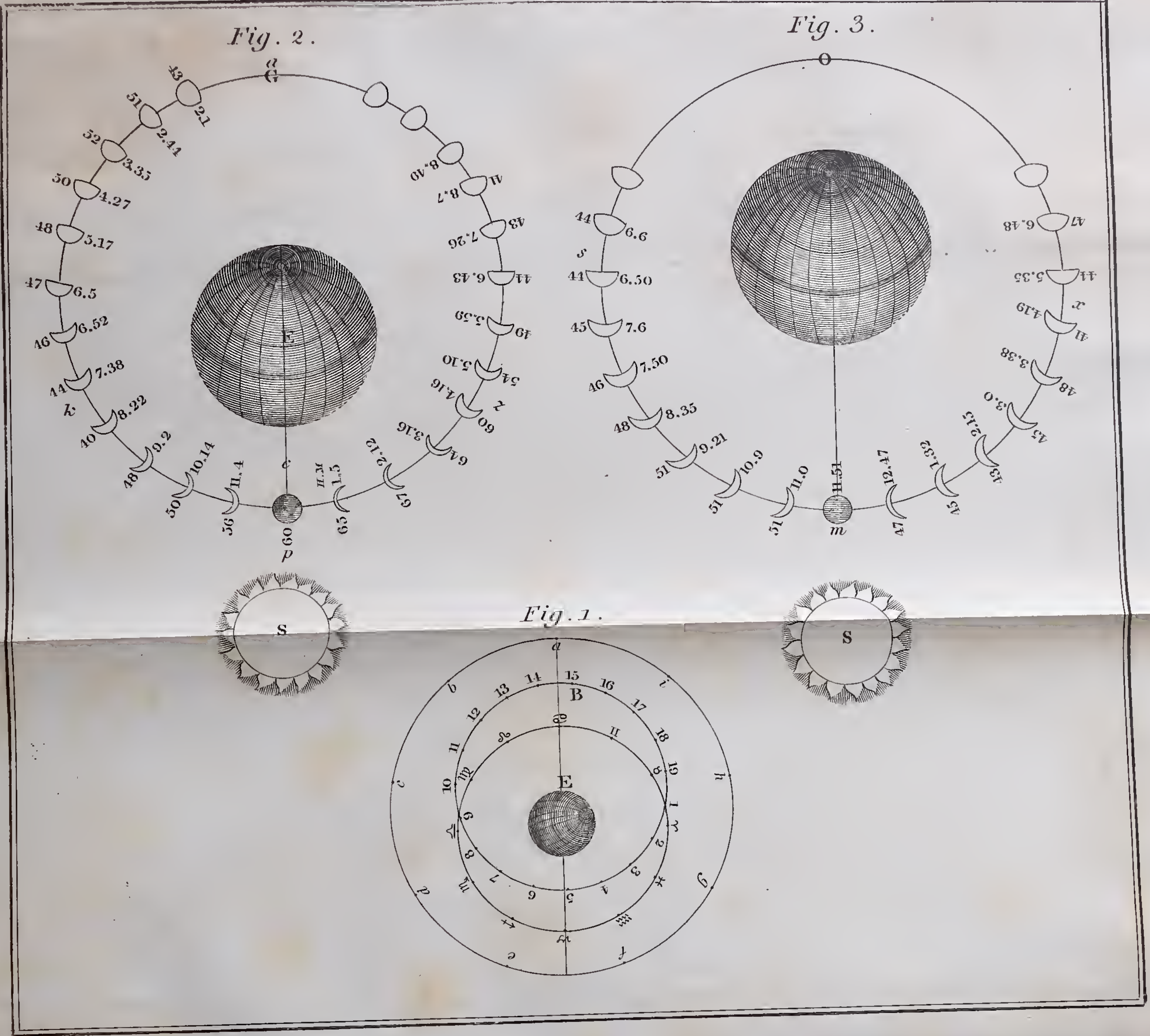
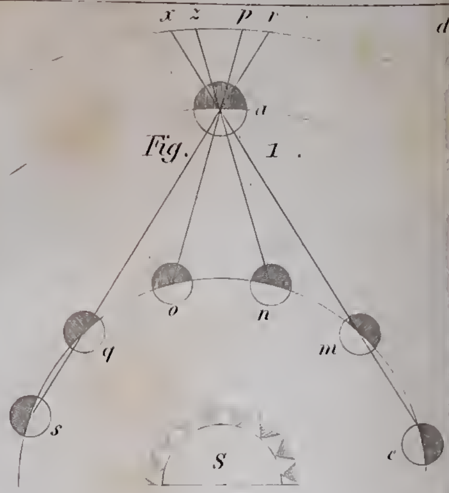


Fig. 2.

Fig. 3.

Fig. 1.

Mutlow Sc. Russell Court.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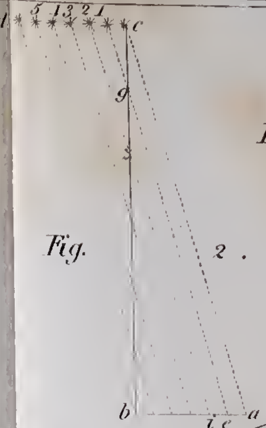
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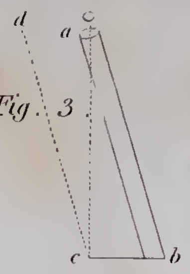
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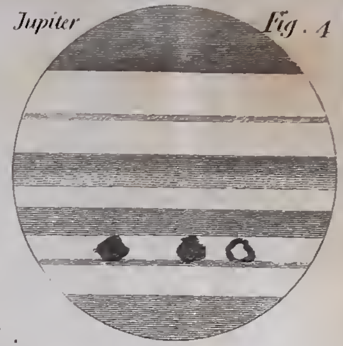
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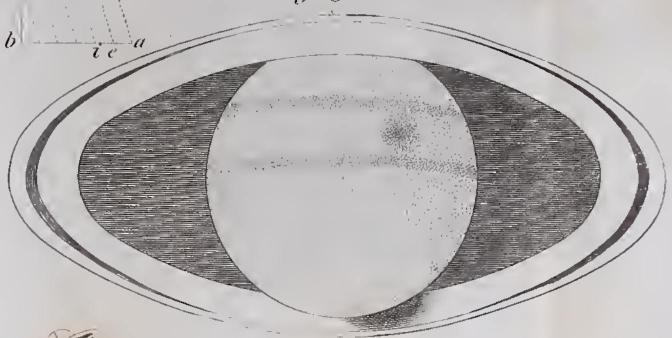
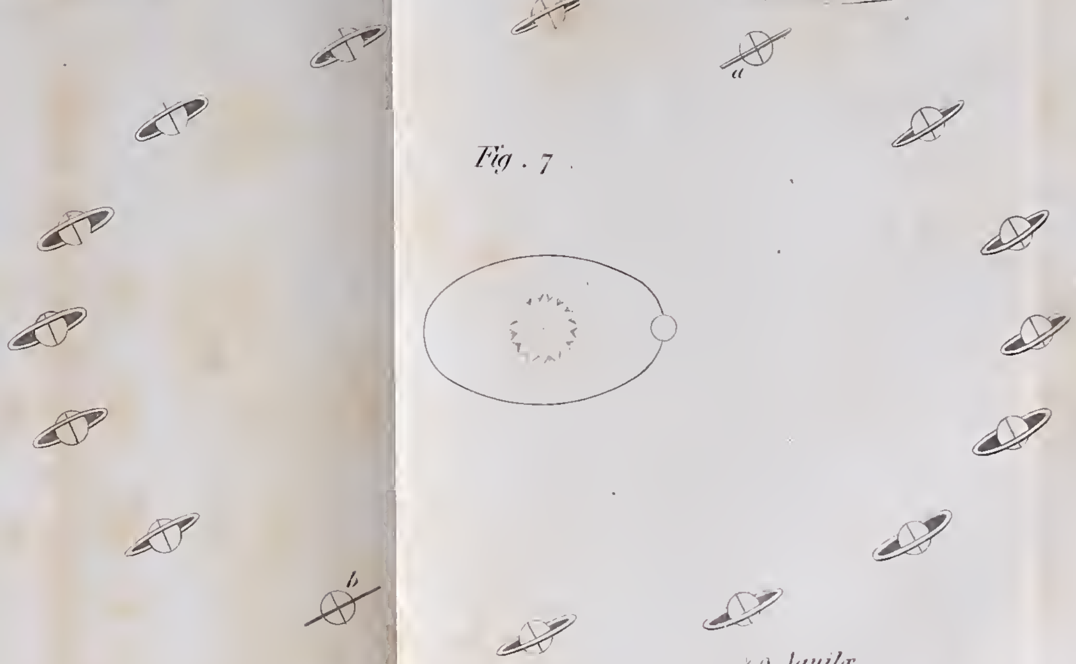


Fig. 5.


Fig. 6.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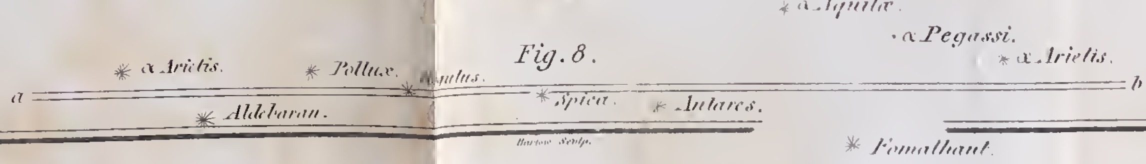


Fig. 8.

Barlow Sculp.

INDEX:

And an Explanation of ſuch uncommon Words, as occur in a Work of this Nature.

INDEX.

INDEX.

INDEX.

being the declination, it is evident, on a bare inſpection of the globe, that both the longitude and declination of the ſtars muſt be perpetually moving towards the weſt, or in the contrary order of the ſigns.

Some ſay that Aries is the golden fleece, fetched by Jaſon from Colchis, and that in memory of the Argonautic expedition, it was placed in the moſt diſtinguiſhed part of the heavens, where the equinoctial point was at that time; and then Aries and its ſymbol ♈ were together, as well as the other twelve ſigns. If ſo, we may calculate how long it is ſince the Argonautic expedition took place: for if the equinoctial point has gone back forty degrees from the ſtars that form the conſtellation Aries, and each degree require ſeventy-two years, then 72 multiplied by 40 gives 2880 years ſince Jaſon ſailed acroſs the Black Sea, to ſteal the woollen manufactory, and bring it into Greece; for, I ſuppoſe, this is the plain Engliſh of that celebrated expedition.

Others make the ram and the bull emblems of the ſeaſon when ſheep and cows bring forth their young. The bull Apis was worſhipped by the Egyptians. The twins, *Gemini*, were originally two goats; May being the ſeaſon when thoſe animals are born, and when the ſun is in that ſign. *Cancer*, the crab, is an animal that creeps backward, and is ſymbolical of the ſun's leaving the northern tropic, at the ſummer ſolſtice, and drawing back towards the ſouth. *Leo*, the lion (called the fourth ſign), repreſents the fury and heat of the dog-days. *Virgo*, the virgin, an Egyptian peaſant originally, with an ear of wheat in her hand as an emblem of harveſt; for the ſun is in that part of the heavens at that ſeaſon. *Libra*, the balance, preſides at the autumnal equinox, and aptly repreſents the medium, or balance, between the heat and cold, long and ſhort days, &c. of winter and ſummer. *Scorpio*, the ſcorpion; autumn affording the cauſe of diſorders by the abundance of its fruits: this unhealthy ſeaſon is ſaid to be typified by this venomous reptile ſpreading out his long claws, and brandiſhing his tail, as if triumphing in the miſchief he can do, and has done. Others ſay, this noxious animal infeſts Egypt upon the ſubſiding of the Nile, and thence became a conſtellation. *Sagittarius*, the archer, repreſented by an arrow, denotes the ſeaſon for hunting. *Capricornus*, the goat, implies the return of the ſun from his ſouthern limit, and climbing up towards the north, as the goat aſcends the mountains. *Aquarius* (a figure pouring out water on the earth) denotes the wet, uncomfortable time of winter: and water being a pabulum of fiſhes, and winter the time when all kinds of food is ſcarce, *Piſces*, the two fiſhes tied together, give intimation of the neceſſary ſeaſon to have them ſo caught.

The ſymbols by which thoſe ſigns are repreſented, bear an awkward likeneſs to the animals themſelves, or parts of them, as,

♈ Aries, the two horns of a ram.

♉ Taurus. Is it poſſible that the two horns, and the face of a bull, could be repreſented by this figure?

♊ Gemini; two ſimilar lines may, indeed, be like twins.

♋ Cancer. I ſuppoſe this ſymbol is meant to convey an idea of the twiſting ſidewiſe motion of the crab.

♌ Leo. Can this be intended for the hip and tail of a lion?

♍ Virgo. What this figure has to do with a virgin, or ears of wheat, is beyond my comprehenſion; yet the figure is ſaid to repreſent three ears of wheat.

♎ Libra. This, no doubt, is intended for a ſcale-beam.

♏ Scorpio. Can this be meant to repreſent the many feet and the ſting of the ſcorpion?

♐ Sagittarius. An archer muſt have arrows.

♑ Capricorn. Why a V and an S ſhould repreſent a goat, I am neither antiquarian nor aſtronomer enough to make out; except, indeed, they repreſent his crooked horns.

♒ Aquarius. This I ſuppoſe is the waves of water. The original ſign (the water-carrier) is ſtill uſed on the continent.

♓ Piſces. The two ſemi-circles are to repreſent two bent or ſtruggling fiſhes, tied together with the ſtroke that croſſes them.

The ſymbols that repreſent the planets are of the ſame character as thoſe of the ſigns.

☿ Mercury. This figure is the caducius of Mercury, i. e. ſhould repreſent two ſerpents twiſted in oppoſite directions round a ſceptre.

♀ Venus. This figure is ſaid to be her looking-glaſs.

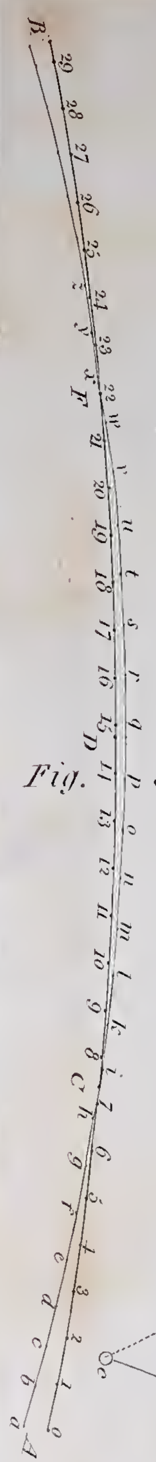
♂ Mars. The God of War, has his ſpear and ſhield united into this figure.

♃ Jupiter. Probably the thunder wielded by the god.

♄ Saturn. This ſymbol is meant for a ſickle or ſcythe, for Saturn was frequently repreſented as time.

♅ Herſchel, the initial of the diſcoverer's name.

FINIS.



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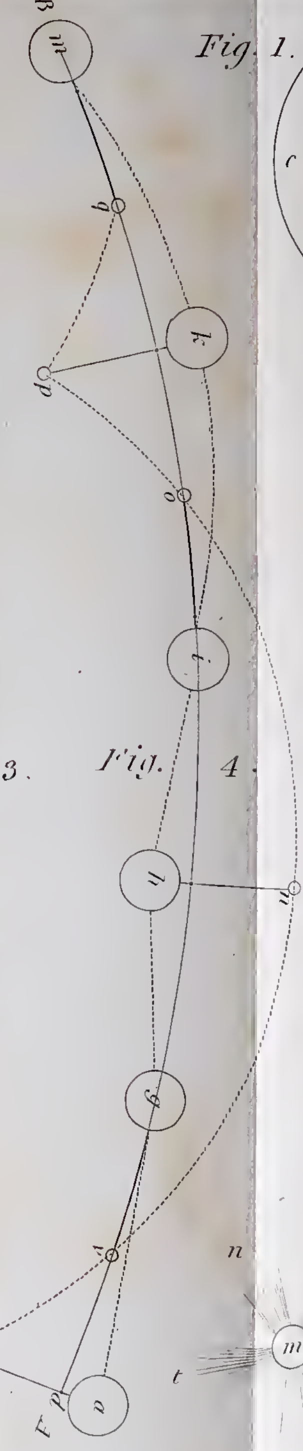

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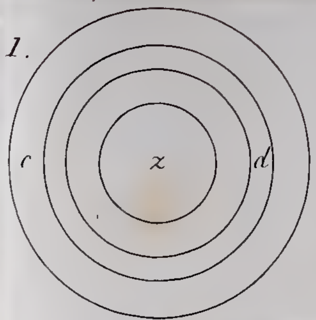

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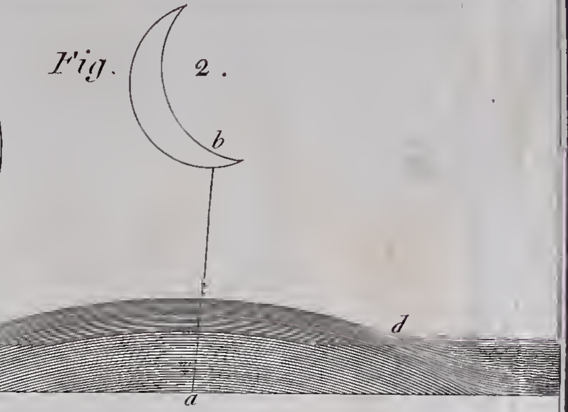

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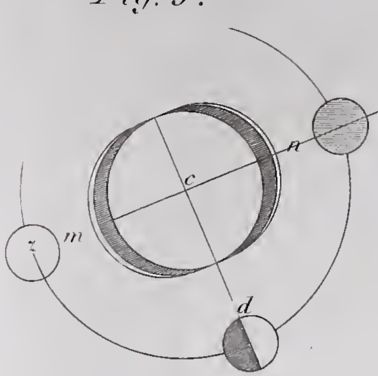

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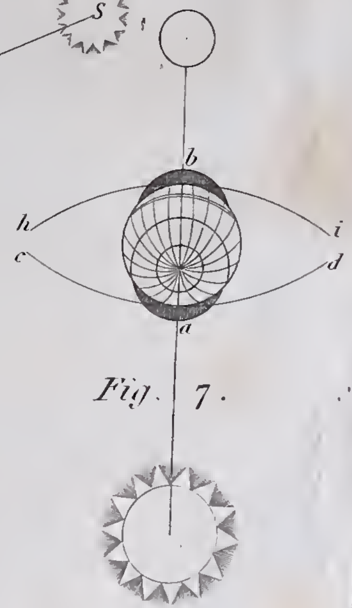

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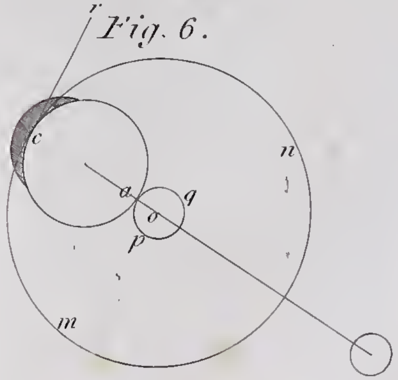

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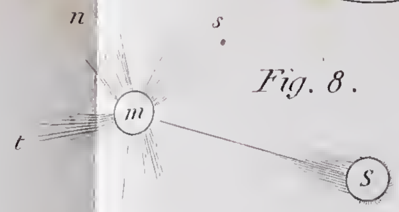

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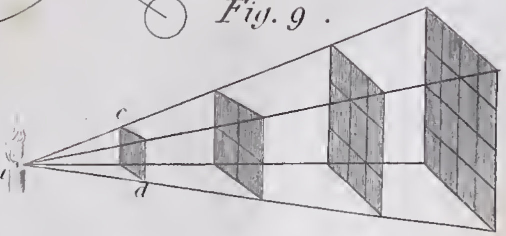
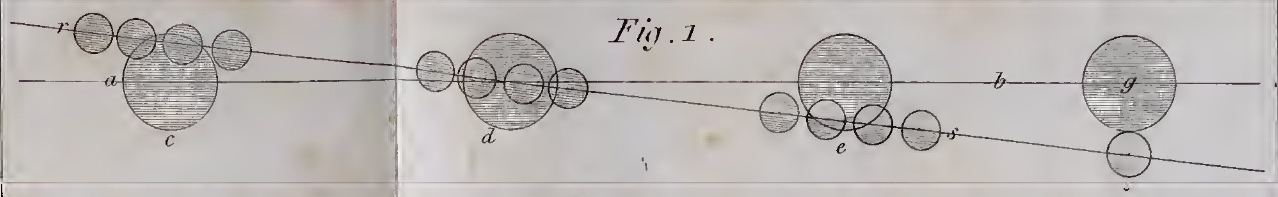


Fig. 9.

Barlow sculp

Fig. 1.



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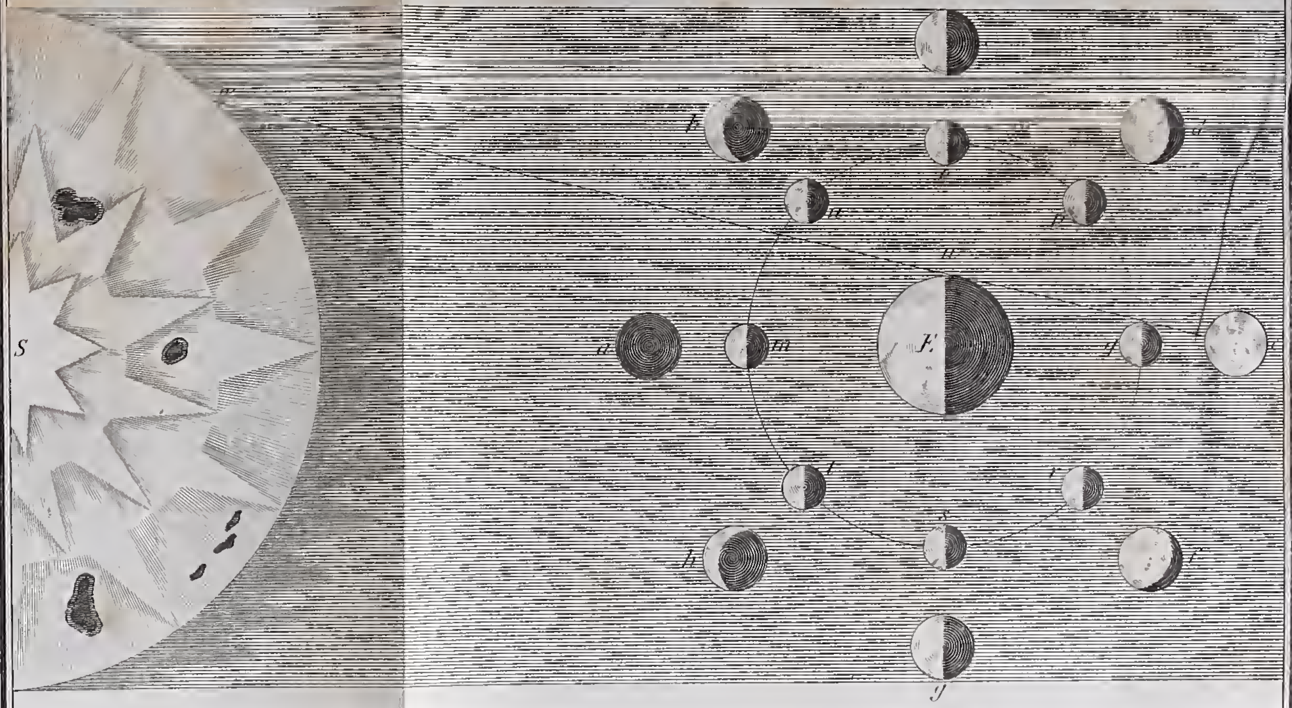

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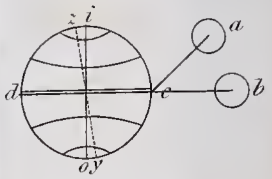

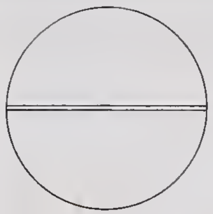

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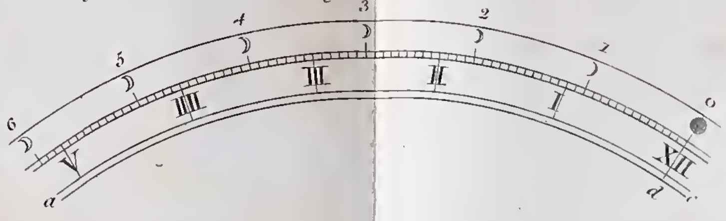

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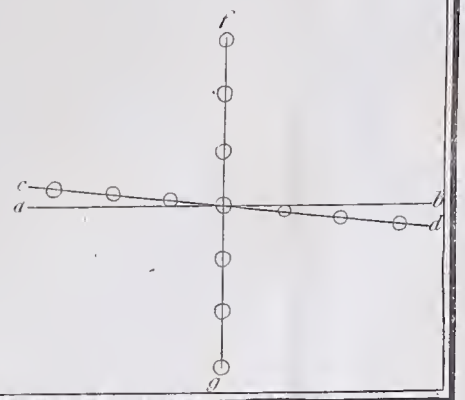
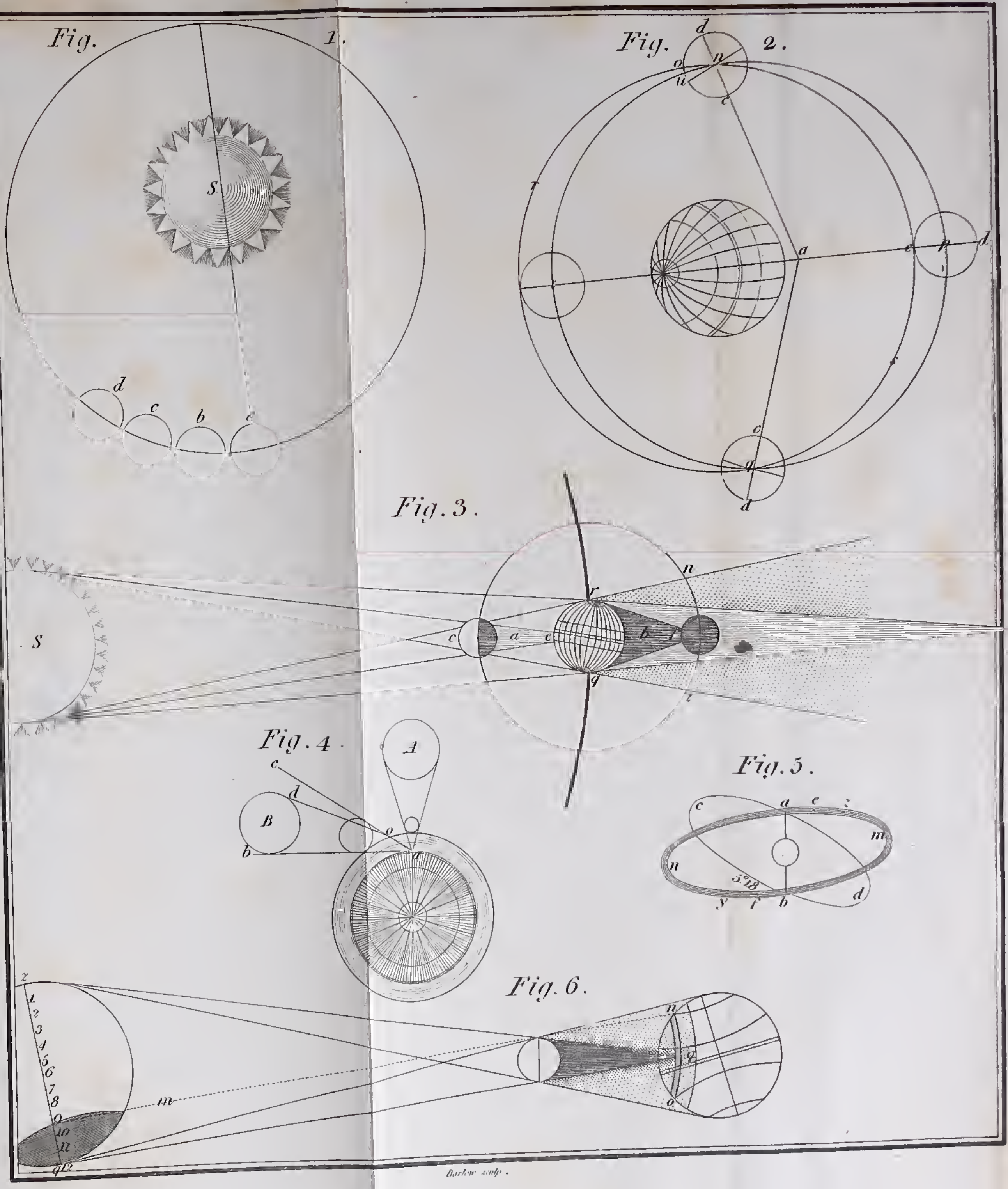
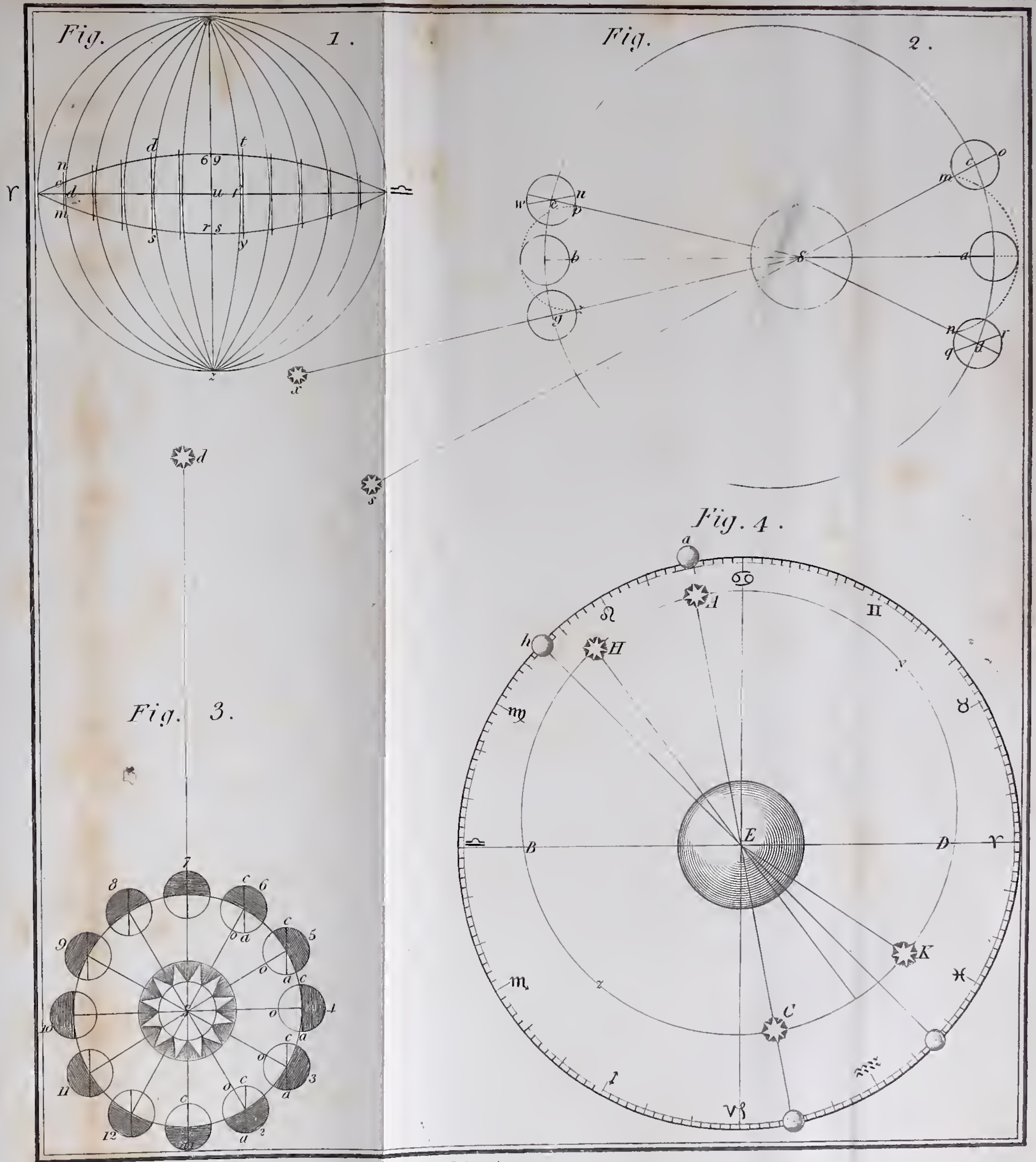


Barlow sculp.



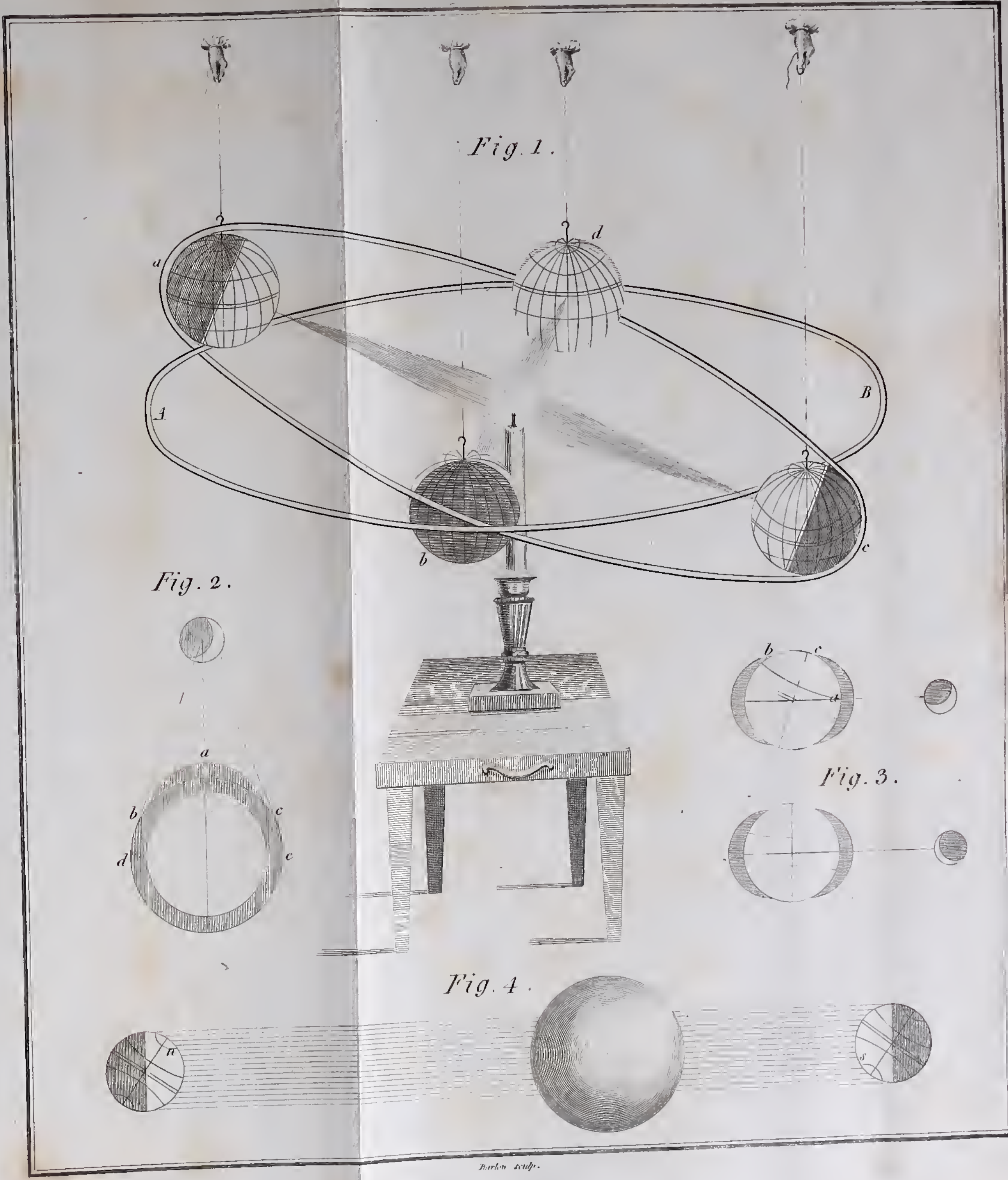
Barlow sculp.

ASTRONOMY.



Barlow sculp.

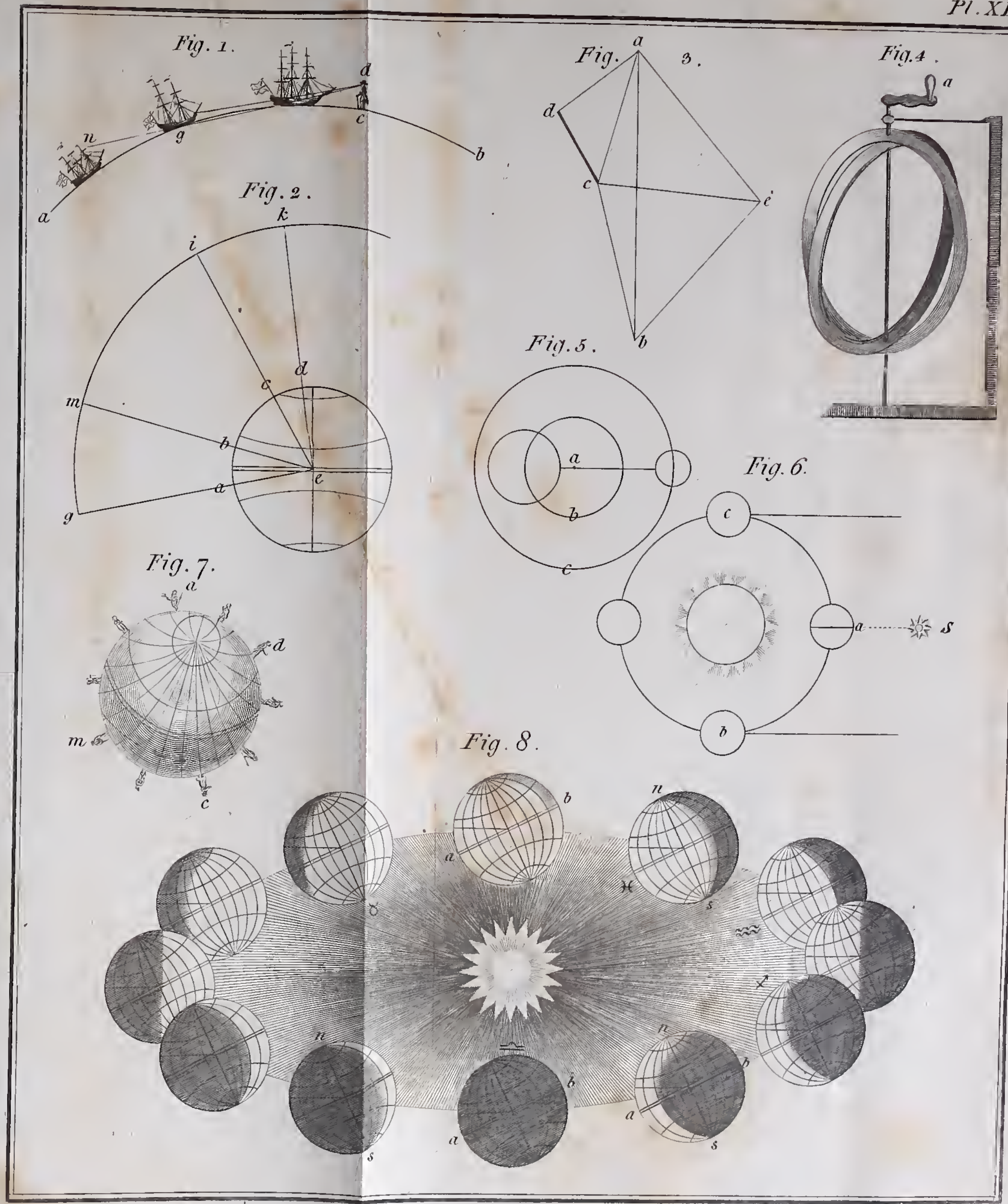
ASTRONOMY. Pl. XLI



Barlow sculp.

ASTRONOMY.

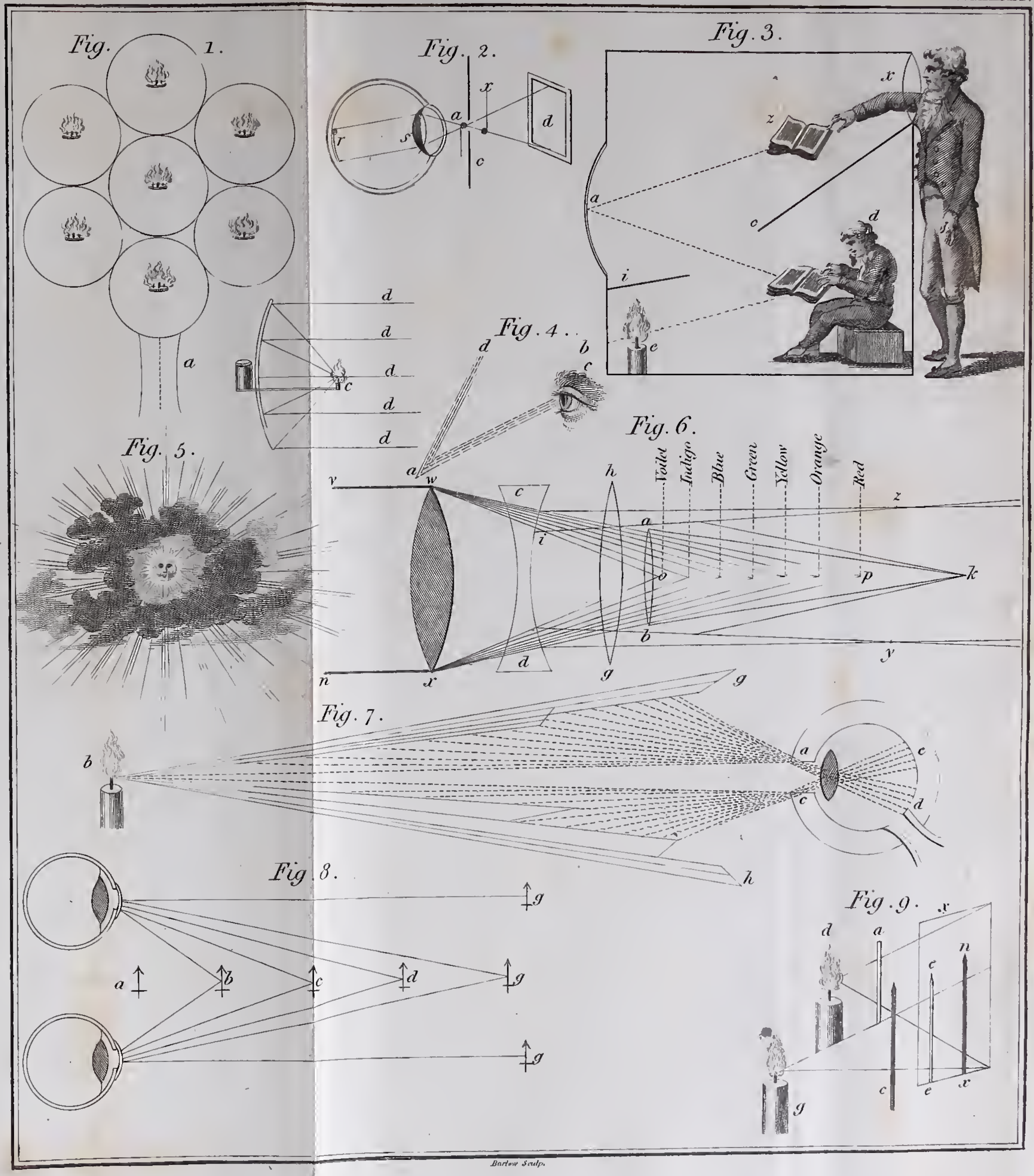
Pl. XL.



Barlow sculp

OPTICS.

Pl. XXXIX.



Barlow Sculp.

OPTICS.

Pl. XXXVI.

Fig. 1.

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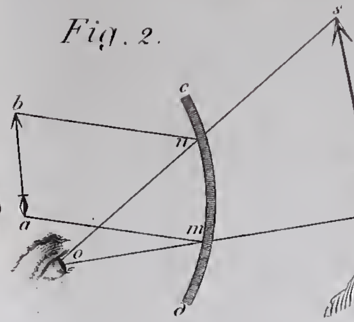
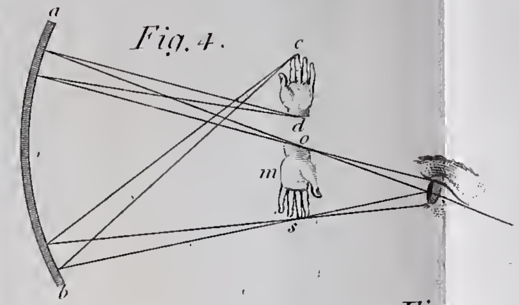


Fig. 3.

Fig. 4.



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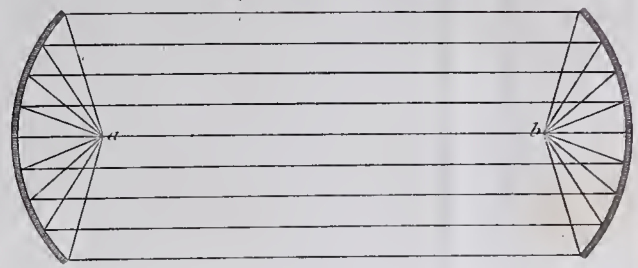

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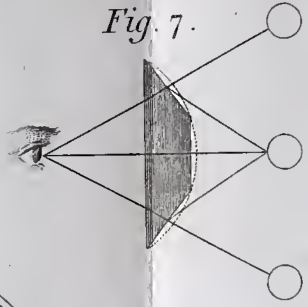

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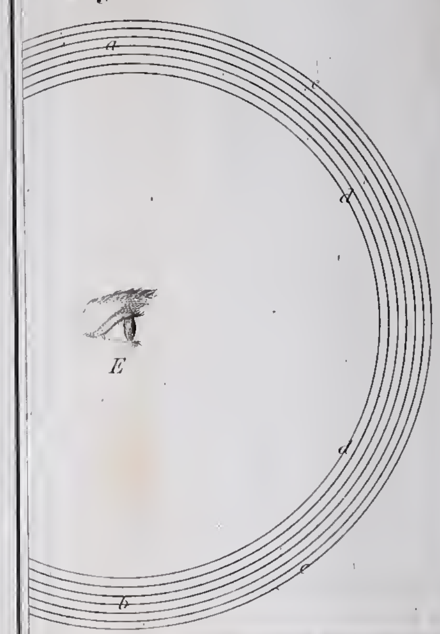

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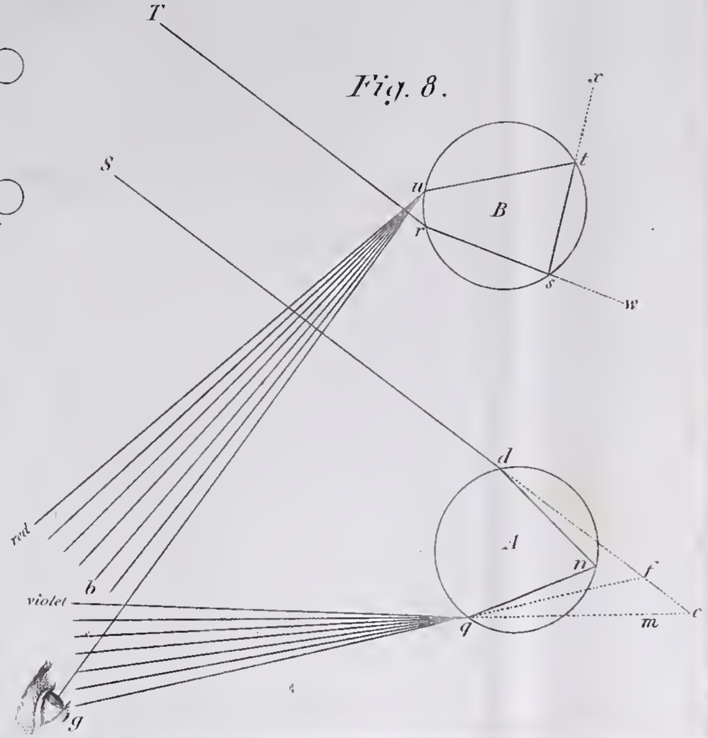


Barlow sculp

Fig. 1.

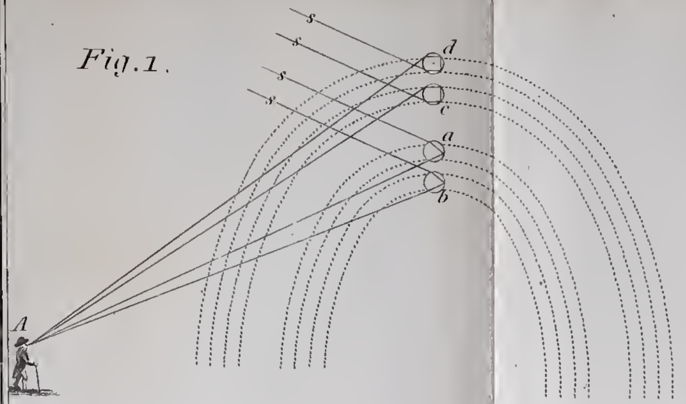
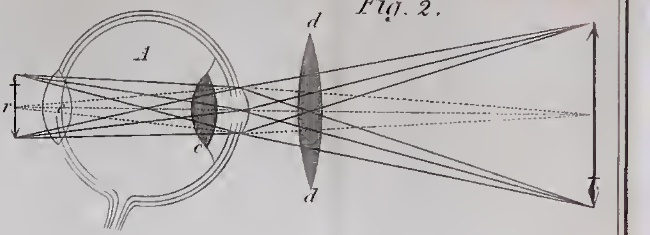


Fig. 2.



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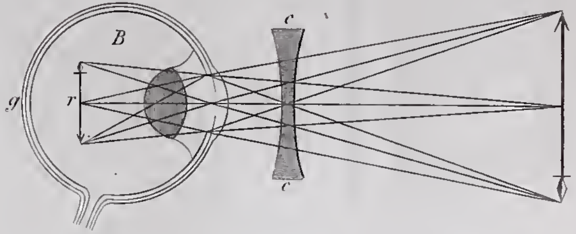

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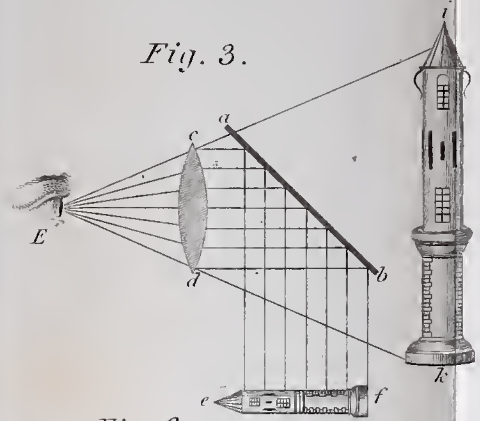

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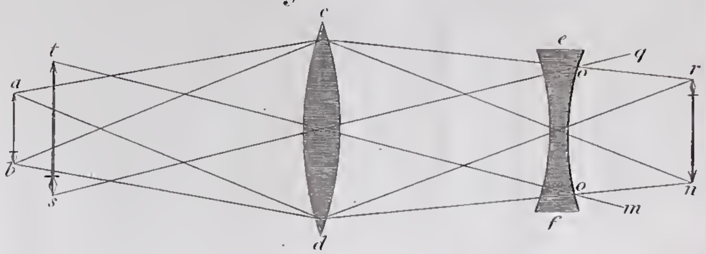

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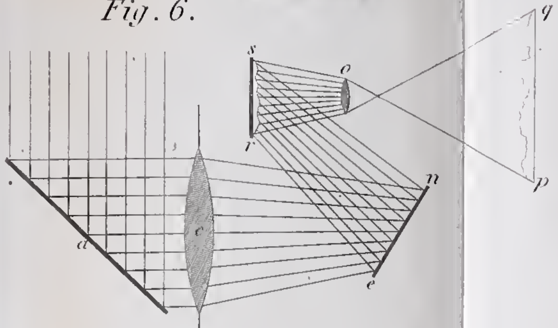

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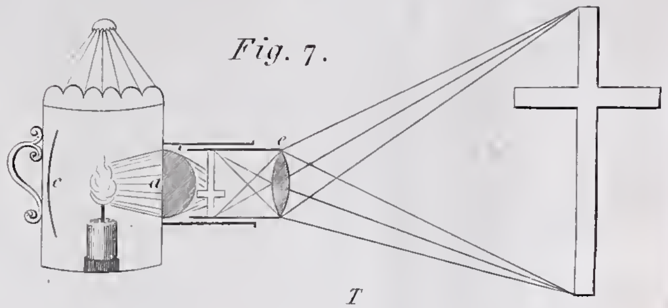

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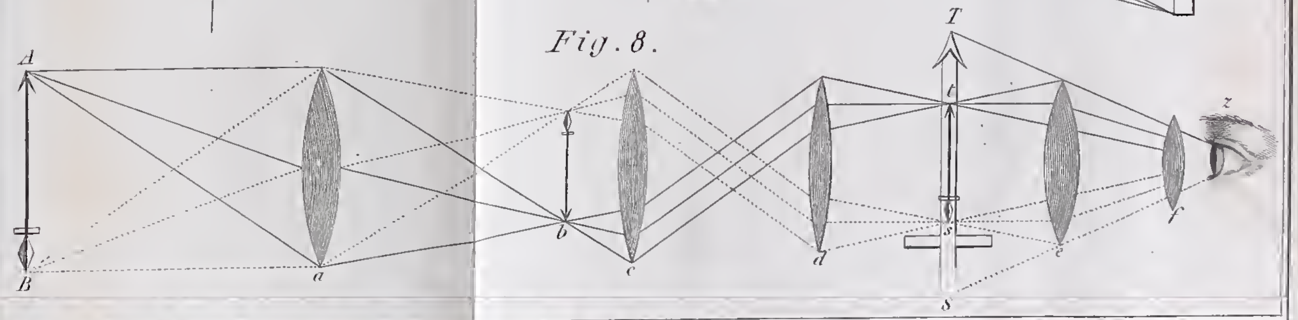
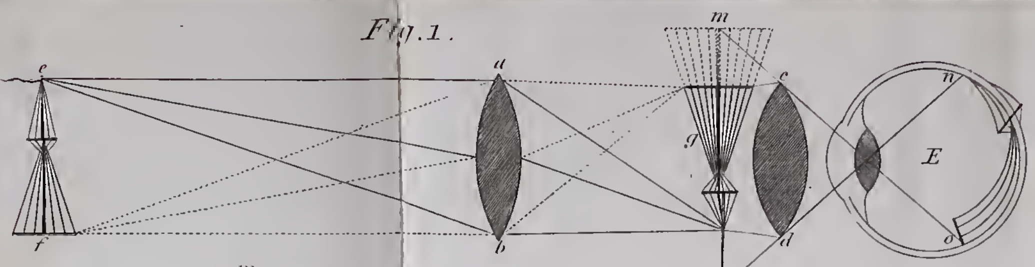


Barlow sculp

Fig. 1.



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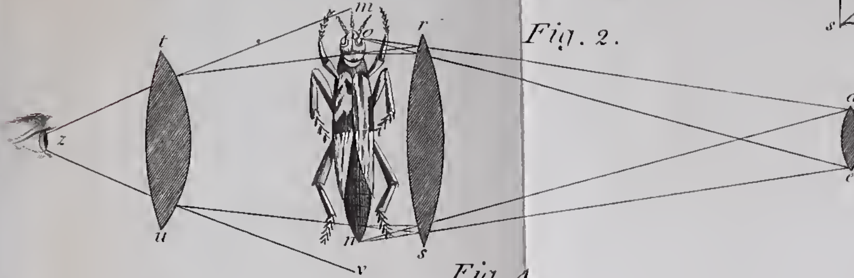

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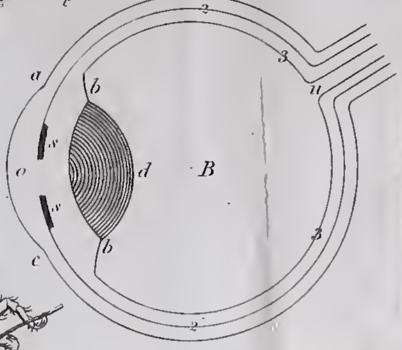

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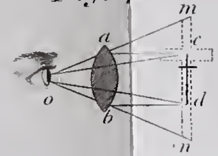

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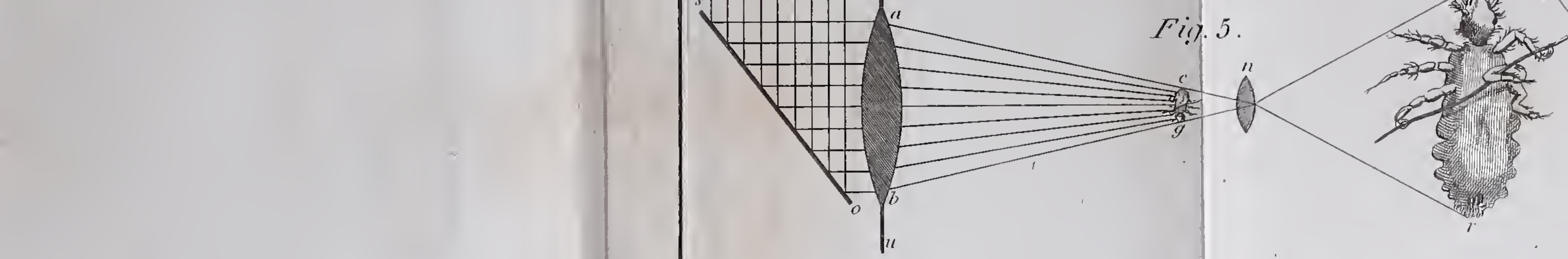

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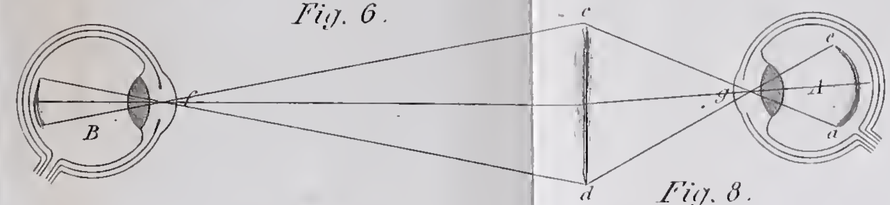

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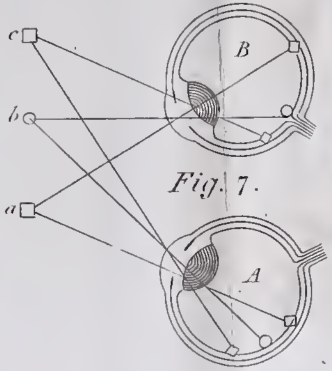

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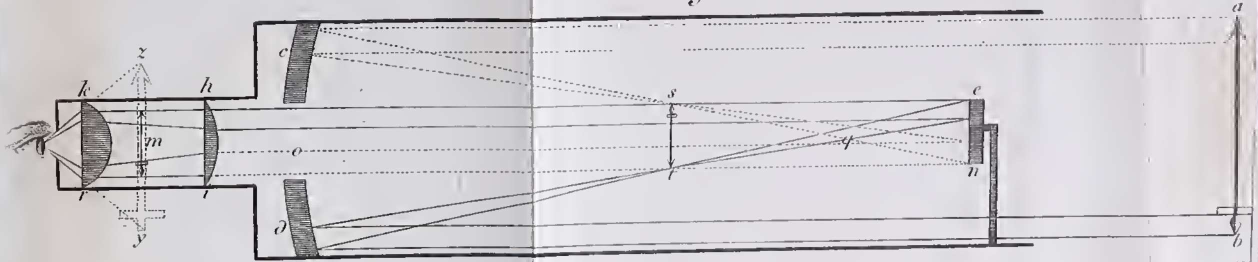

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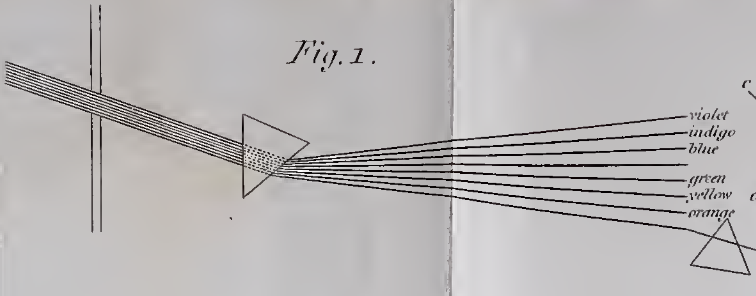
Fig. 1.



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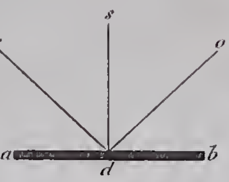

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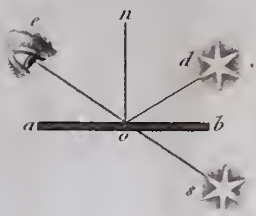

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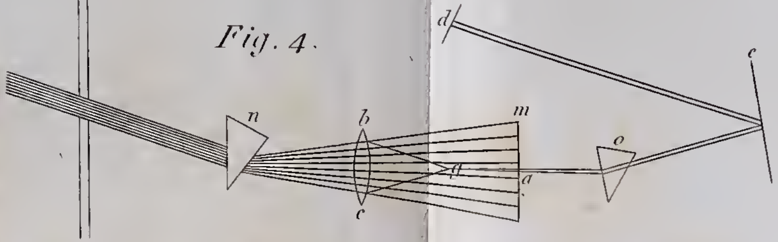

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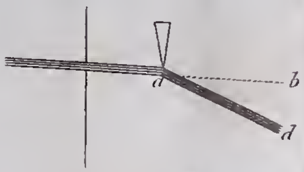

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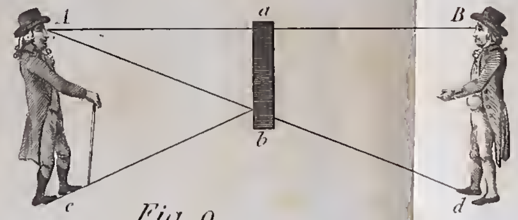

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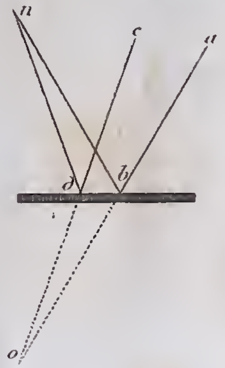

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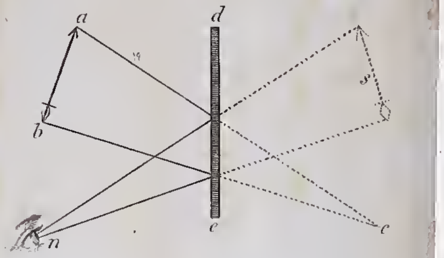

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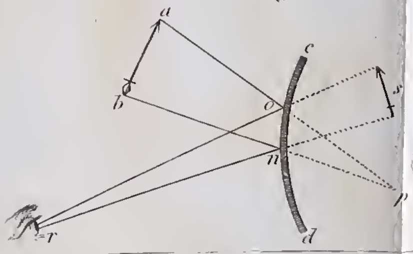

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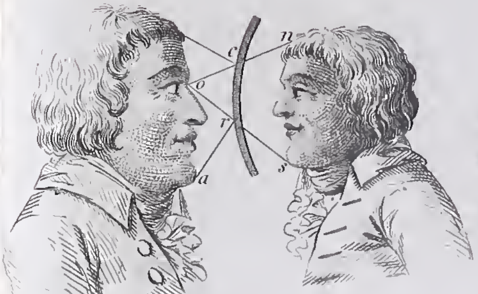

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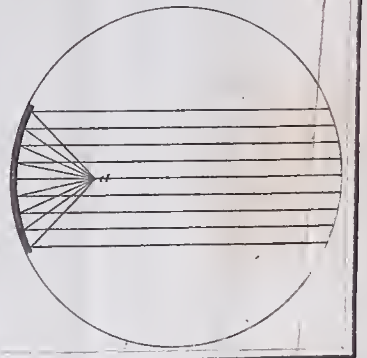
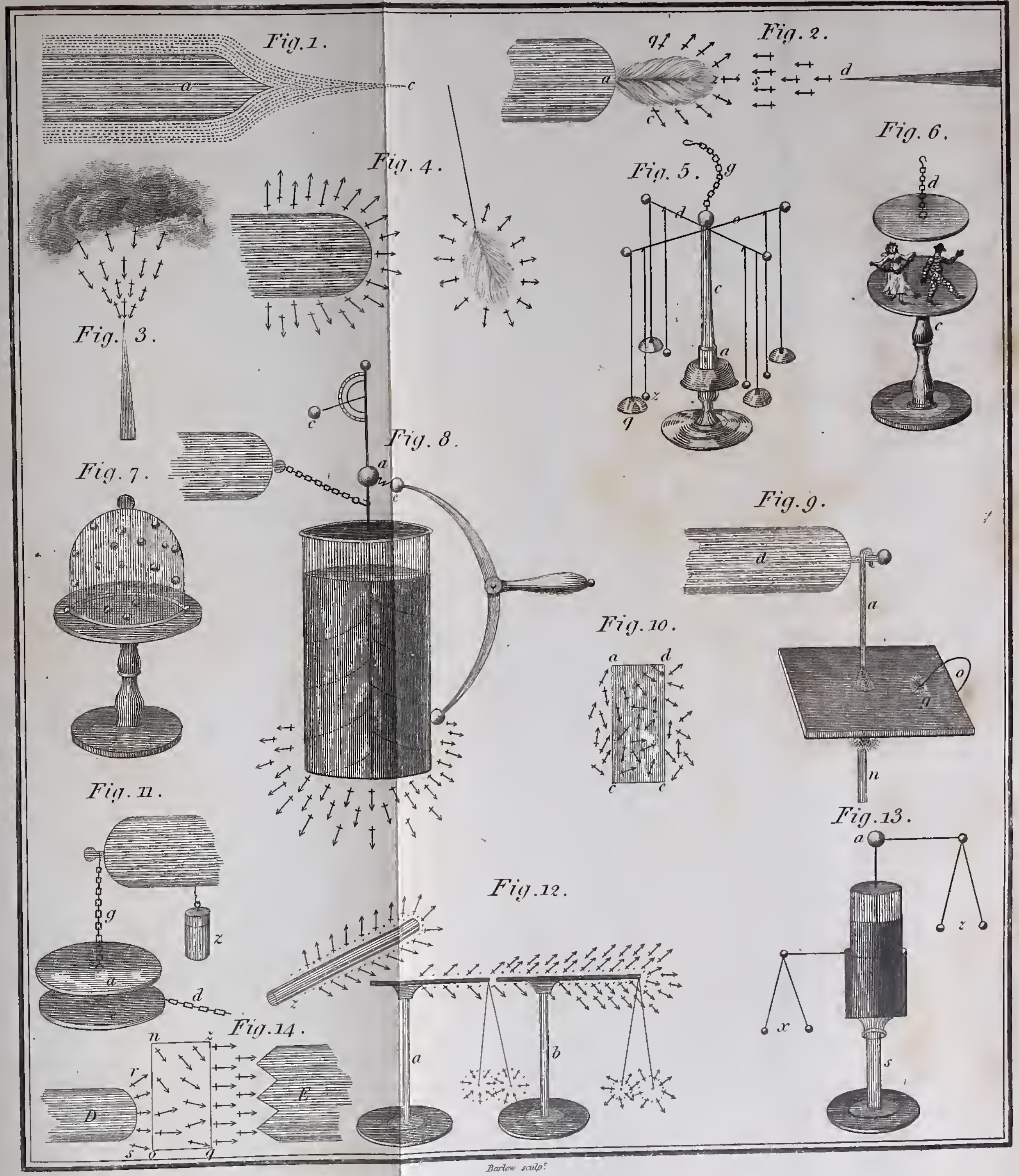


Barlow sculp.

ELECTRICITY.

Pl. XXX.



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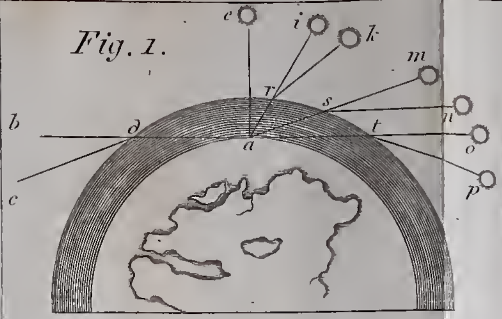

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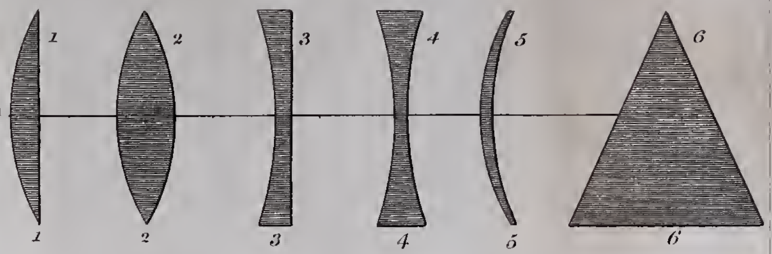

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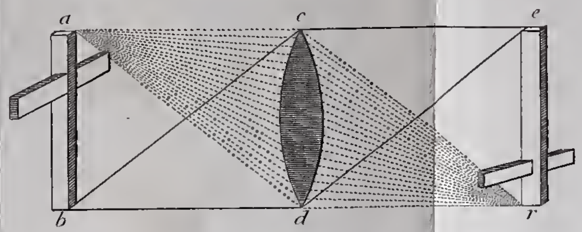

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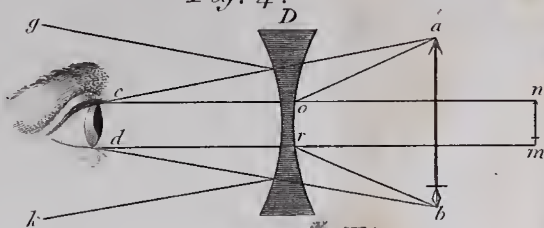

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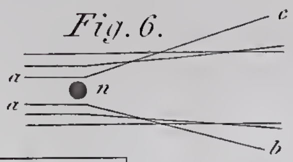

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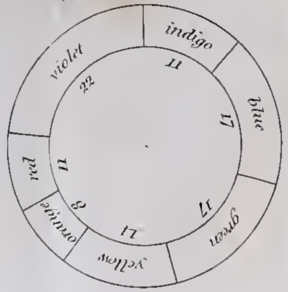

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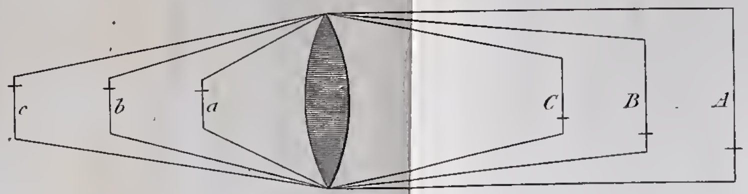

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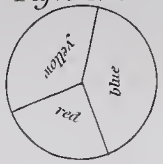

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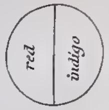

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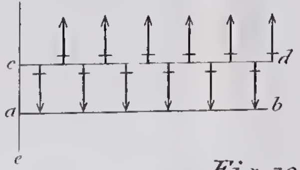
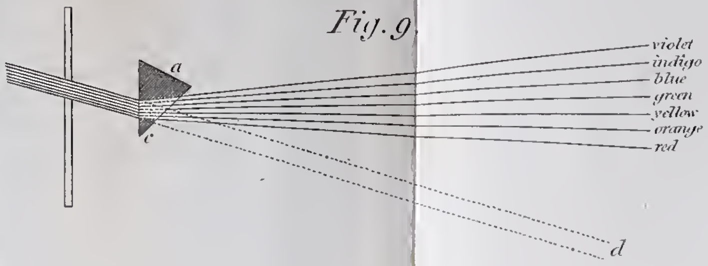


Fig. 8. No. 2.

Fig. 9.



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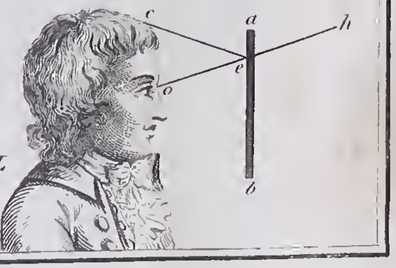

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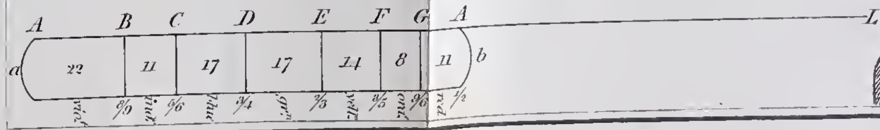

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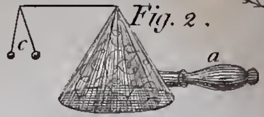
ELECTRICITY.

Pl. XXXI.

Fig. 1.

Fig. 2.



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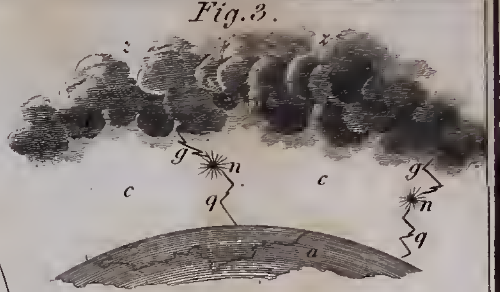


Fig. 4.

Fig. 8.

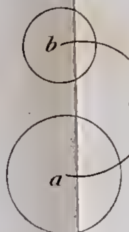
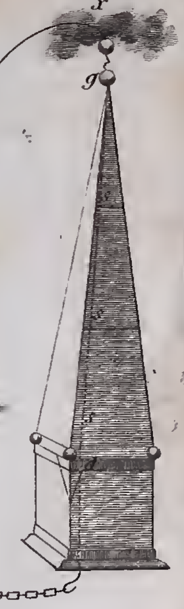


Fig. 9.

Fig. 10.



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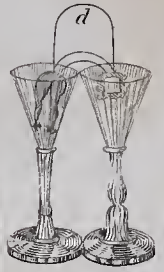

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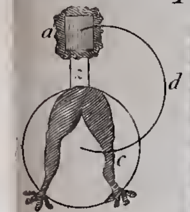

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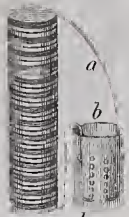

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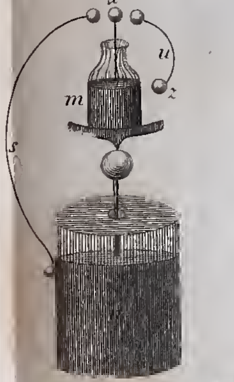

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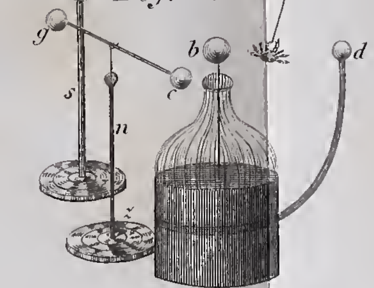


Fig. 14.

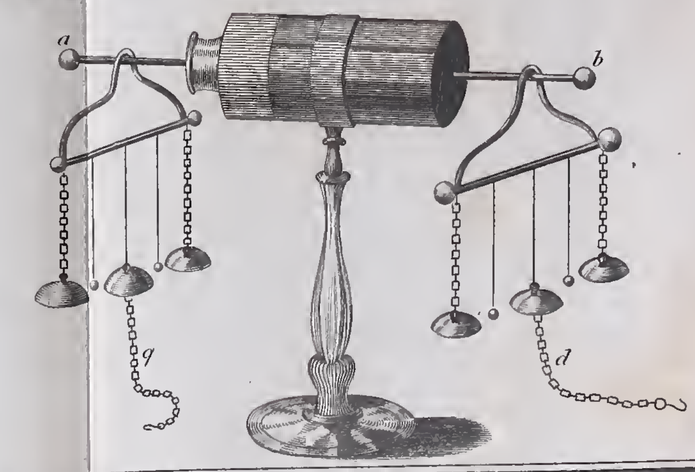
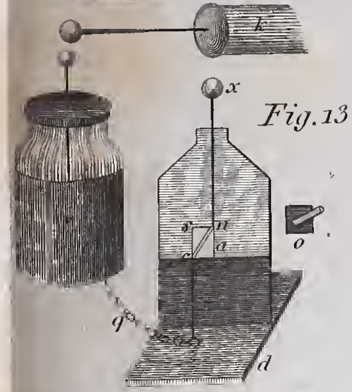


Fig. 13.



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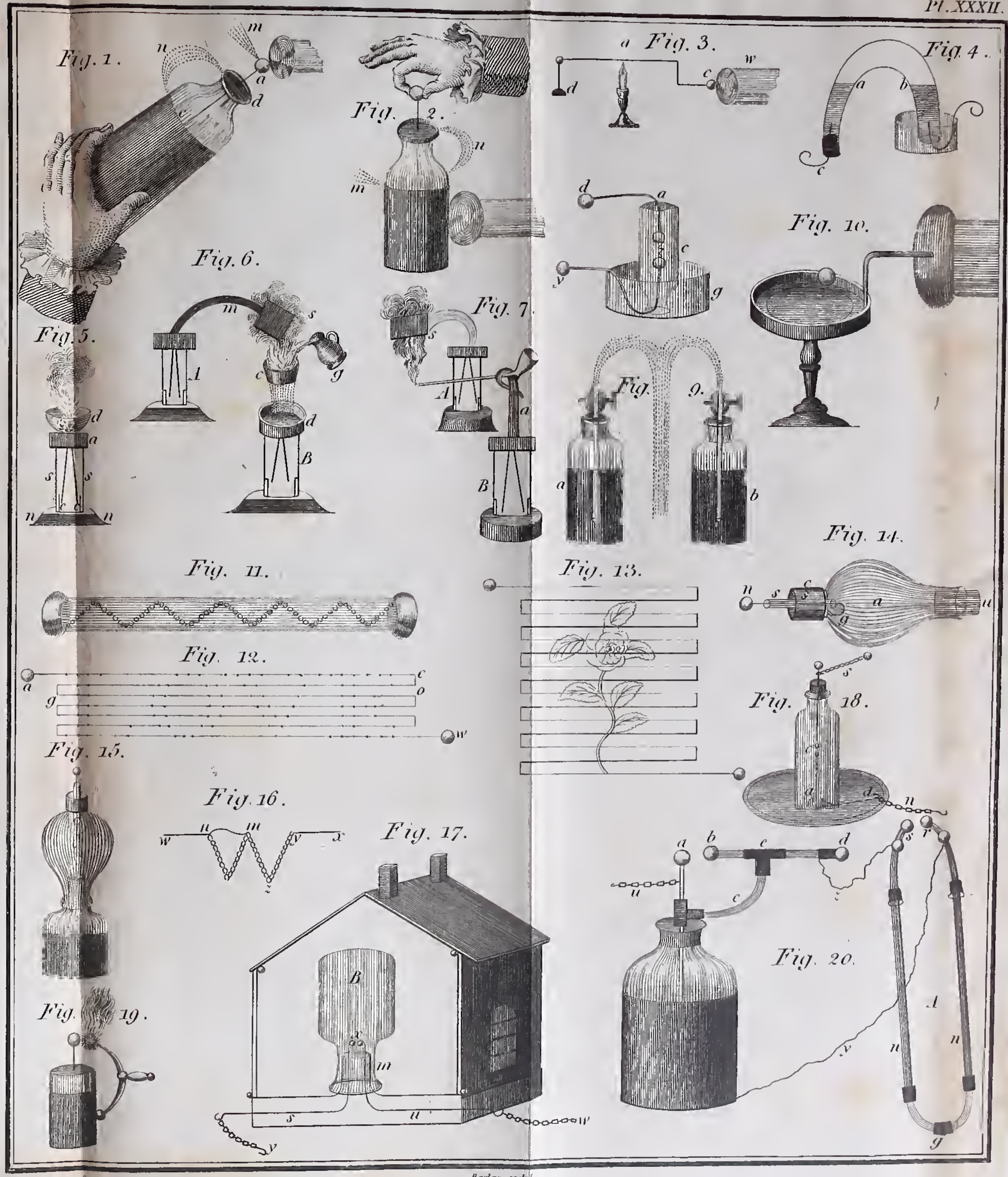
ELECTRICITY.

Pl. XXXII.



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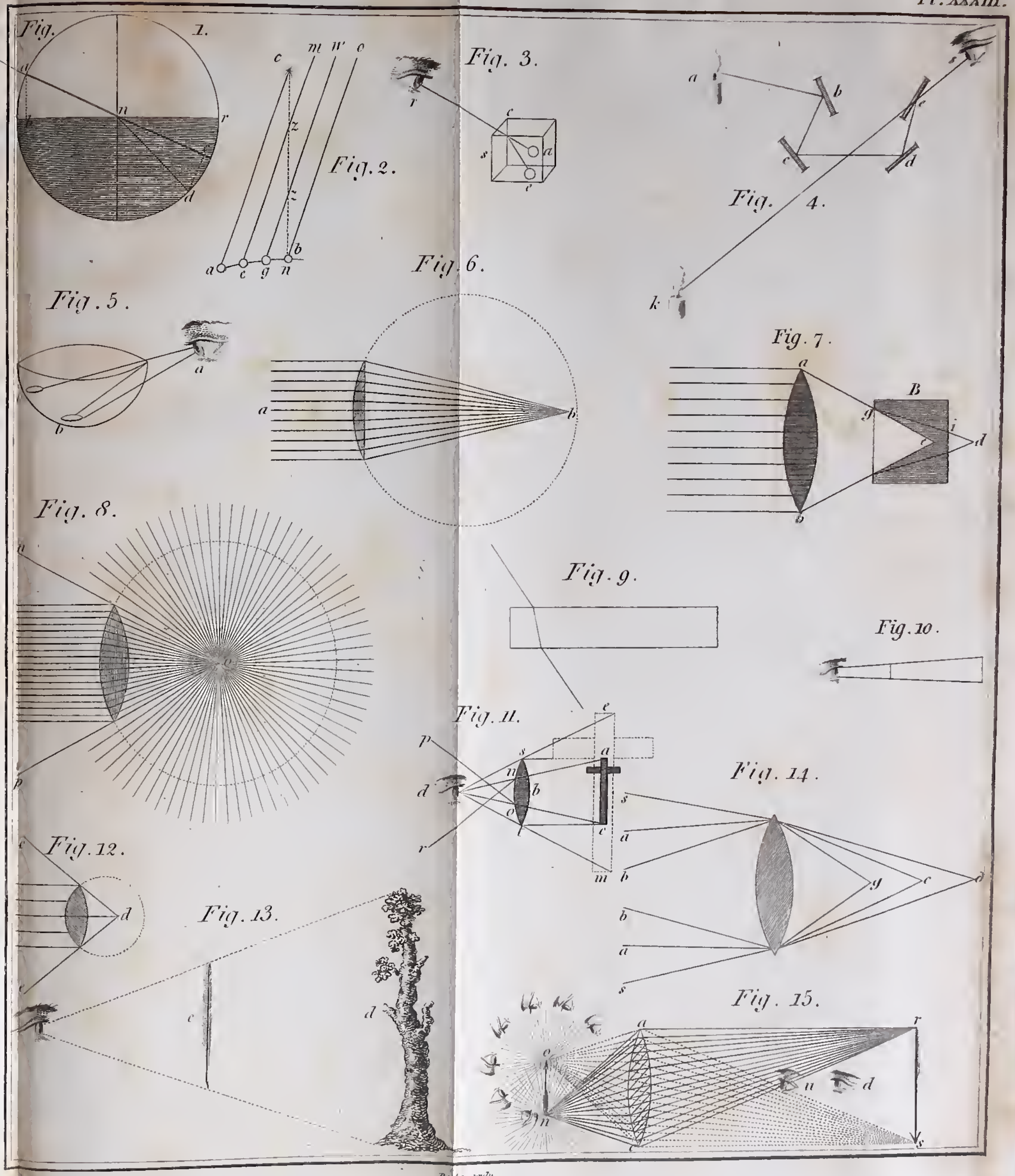
OPTICS.

Pl. XXXIII.



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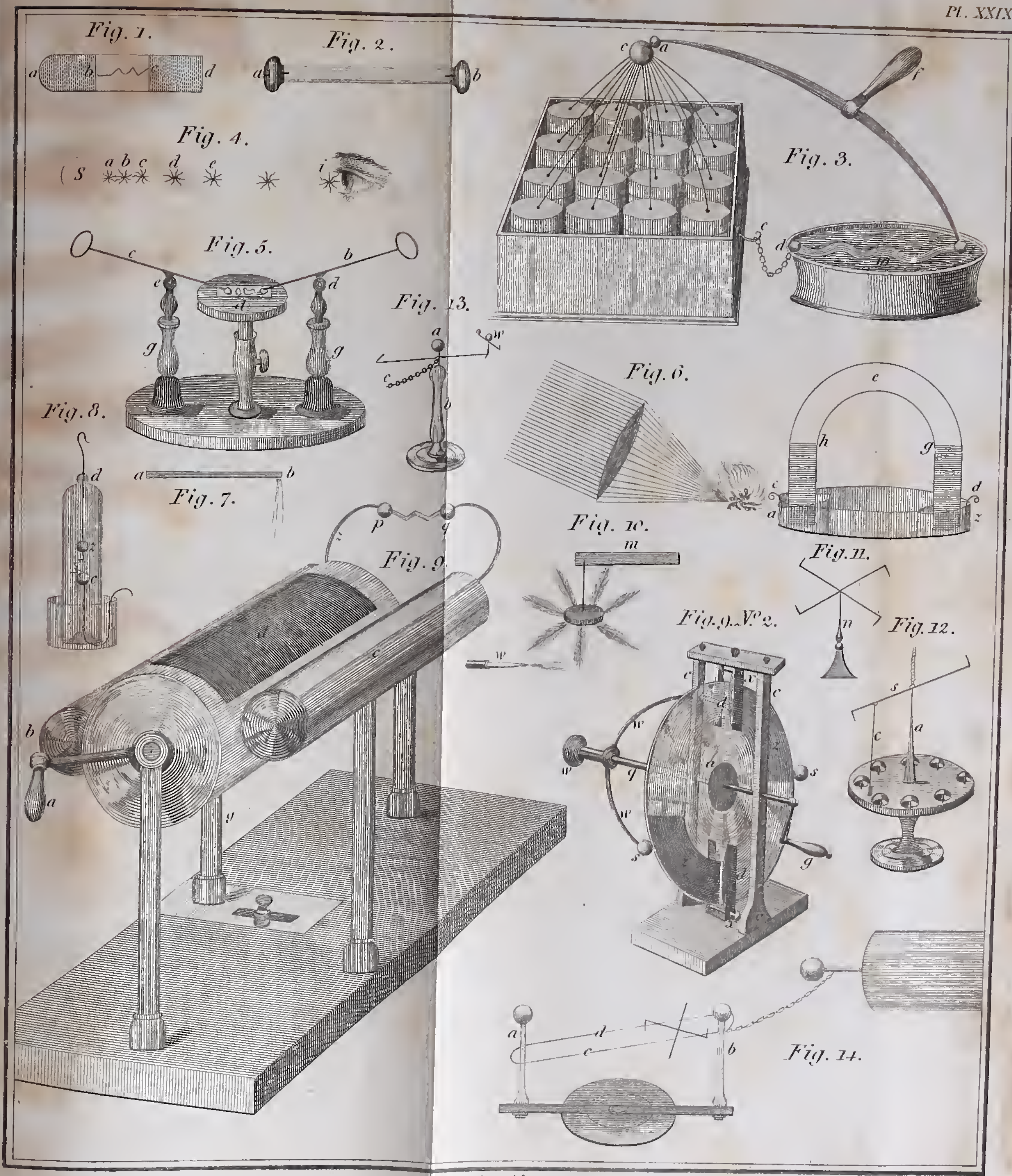
ELECTRICITY.



Barlow sculpt

INDEX.

INDEX.

INDEX.

INDEX.

INDEX.

INDEX.

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